

# Develop an Air Emission Inventory for Potential Point Sources in Northern Key Economic Zone and Simulate Its Impacts on Air Quality in Hanoi City, Vietnam

**Bang Quoc Ho<sup>1,2\*</sup>, Khue Vu<sup>1</sup>, Nguyen Thoai Tam<sup>1</sup>, Le Ngoc Cau<sup>3\*</sup>**

1. Institute for Environment and Resources (IER), Ho Chi Minh city 700000, Vietnam

2. Department of Department of Academic Affairs, Vietnam National University, Ho Chi Minh city 700000, Vietnam

3. Vietnam institute of meteorology, hydrology and climate change

†Email: caukttv@gmail.com <sup>3\*</sup>, hqbang@vnuhcm.edu.vn <sup>1\*</sup>

## **Abstract**

The Northern Key Economic region of Vietnam is a dynamic economic center that is an important economic locomotive of the North and the whole of Vietnam. In this area, large industrial parks are concentrated, attracting many large FDI projects. Key industries: cement production, cars - motorcycles, electronics,... Economic development entails environmental problems. The industrial sector has been identified as the number one driving force driving the growth of Hanoi city and neighboring provinces. Therefore, industrial development is one of the main causes of environmental pollution. In addition, the growth rate of industry in neighboring provinces significantly affects the air quality in Hanoi city. Some factories in Vinh Phuc, Hung Yen, Bac Ninh and Hai Duong provinces have large sources of gas emissions, potentially affecting air quality around Hanoi city. Monitoring results show that air pollution in Hanoi city is mainly caused by dust pollution, especially PM<sub>2.5</sub> superfine dust. This is a very harmful dust to health; it is necessary to determine the cause and control solution. Therefore, the objectives of this study are: (1) inventory of potential emissions sources for industrial activities in the northern key economic region around Hanoi; (2) Simulate air spread by AERMOD model to get an overall picture of the industrial impact of surrounding provinces in Hanoi city; (3) Propose solutions to manage air quality for the city in the coming time. Simulation results for pollutants with the highest concentration of NO<sub>x</sub> for 1 hour, 24 hours and the average of the year is 7.94; 1.02; 0.222 (μg/m<sup>3</sup>); of CO for 1 hour and 8 hours are 27.616; 8.89 (μg/m<sup>3</sup>); of SO<sub>2</sub> for 1 hour, 24 hours and the average of the year is 4.005; 0.288; 0.038 (μg/m<sup>3</sup>); of PM<sub>2.5</sub> for 1 hour, 24 hours and the average of the year is 0.32; 0.023; 0.003 (μg/m<sup>3</sup>); of PM<sub>10</sub> in 1 hour, 24 hours and year average are 1.03; 0.074; 0.098 (μg/m<sup>3</sup>).

**Keywords:** *Air Pollution; Air Emission Inventory; Northern Key Economic Zone (NKEC); Potential Sources; Industry; Hanoi*

## **1 INTRODUCTION**

Hanoi is the capital, the socio-economic center of the country and the nucleus in the key economic region of the North. This is also a locality with developed industry. According to the approval of the Hanoi Capital Construction Master Plan to 2030 and a vision to 2050, Hanoi city will have 33 industrial parks (KCN), hi-tech parks (KCNC) with a total area of about 8,000 ha and 159 industrial clusters (CCN) with a total area of 3,204.31 ha, of which 69 CCN are multi-industry, 90 CCN have village nature. Currently, Hanoi has 9 operating KCN, of which 8 KCN are 100% filled and operating well and 70 CCN are operating stably. With more than 13,000 industrial production and service establishments in the area, the construction industry is contributing 20-23% of the city's economic proportion. Hanoi. This is one of the localities receiving the most foreign investment, with USD 1,681.2 million and 290 projects. The city is also the location of 1,600 foreign representative offices, 14 industrial parks and 1.6 thousand industrial production facilities. Therefore, the total emissions in the industrial sector also account for an important proportion.

Therefore, industrial development is one of the main causes of environmental pollution. According to the State of the Environment Report of the National and of Hanoi city, period from 2016 - In 2020, dust pollution is still a matter of concern in Hanoi. Average annual value of dust parameters  $PM_{2.5}$  and  $PM_{10}$  at all automatic and continuous air environment monitoring stations in Hanoi in the period of 2018 - 2020 have all exceeded the threshold of QCVN 05:2013/BTNMT from 1.1 to 2.2 times, of which the highest is 2019. In 2019, Hanoi recorded 6 waves of fine dust air pollution at the level altitude, of which 5 occur in the winter months.

Controlling emission sources is one of the effective measures when air pollution is extremely difficult to control. Emission inventory, especially building a database of waste sources, is an important basis for managers to understand emissions and control pollution levels. It also helps to identify the sources of emissions as well as the type of activities that emit air pollutants in the management area; help determine the extent and scale of the sources of waste. In the world, there are also many studies on emissions inventory and air propagation simulation, research activities can be mentioned such as: Research by Awkash Kumar, Anil Kumar Dikshit and Rashmi S. Patil on the use of using a combination of WRF meteorological model and AERMOD air propagation model to assess air quality due to industrial activities of Mumbai city, India; Research by Jieyun Ma, Honghong Yi, Xiaolong Tang, Yan Zhang, Ying Xiang, Li Pu (2013) on using the AERMOD model to simulate possible future air pollution scenarios in order to bring emission control policies to China.

In Vietnam, emissions inventory is still a relatively new concept. Enterprises and production facilities are still not fully aware of the purpose and meaning of inventory activities, so there is still an avoidance mentality. The economy is growing, factories are expanding, controlling air pollution from industrial activities is an important task. In this study, it serves the orientation, assessment and development of the Air Quality Management Plan, and the implementation of air quality control for Hanoi city. This is also the foundation for managers to identify and initially develop regulations on Quota, the carbon credit market under the Law on Environmental Protection 2020. Currently, there have been many applied studies, but still not yet included in the air quality management system. Research activities, including the following case studies: Authors group Ho Minh Dung, Ho Quoc Bang, Le Viet Thang (2018), on the use of air quality simulation model TAPM - AERMOD Evaluation of the spread of air pollution from animal husbandry activities in Tan Thanh district, Ba Ria - Vung Tau province; Research by Huy, 2017 on the calculation of exhaust gas emissions (EI) for thermal power plants (TPPs) and industrial activities in Vietnam in 2010.

## **2 MATERIALS AND METHODS**

### **2.1 Research Area**

The study was carried out within 5 provinces/cities including: Hanoi city, Bac Ninh, Vinh Phuc, Hung Yen and Hai Duong province. Hanoi city is located to the northwest of the center of the Red River Delta, adjacent to 9 provinces, to the North is Thai Nguyen, Vinh Phuc; the South borders Ha Nam, Hoa Binh; the East borders Bac Giang, Bac Ninh and Hung Yen; The West borders Hoa Binh and Phu Tho (Figure 1). Hanoi city has a natural area of 3,358.6 km<sup>2</sup>, including 30 district-level administrative units, including 12 districts, 17 districts, 1 town with 579 commune-level administrative units, including 383 communes and 175 wards and 21 towns. There are industrial plans in every district, town and town. Industrial development zones are concentrated in districts and scattered in other areas. All industrial zones and clusters have favorable locations, creating attractiveness and high competition.

### **2.2 Research Methods**

#### **2.2.1 Investigations and Surveys**

The research team collected information from 16,562 facilities and processed the collected data, the results were 322 establishments have potential emission sources to serve the calculation of emissions of air pollutants (ONKK) for industrial sources. These industrial facilities are all establishments that use fossil fuels, other fuels for combustion, and facilities that do not use fuels but generate pollutant gases in the production process (e.g., wood-related manufacturing facilities that generate dust, or seafood processing facilities that may emit VOCs). The production facilities are randomly surveyed, including large manufacturing companies, factories in industrial zones, these factories are far from

Hanoi city from 30km or more. Surveyed industries such as packaging production, cement products, auxiliary products for printing, textile, electronics, metallurgy, wood, mechanical processing, wood production, paint, construction materials (construction bricks), paper production, CaCO<sub>3</sub> light powder, production and supply of electrical wiring, manufacture of electronic components, tanning, production of animal feed, fertilizer, food. The survey results include information about fuel, raw materials, production process, exhaust and waste treatment systems, and plant capacity. In addition to survey information, the group has access to environmental reports and environmental impact assessments, environmental monitoring data.



FIGURE 1 BOUNDARY MAP OF NORTHERN PROVINCES

TABLE 1 NUMBER FACTORIES WERE MADE AND DATA COLLECTION

No.	City/Province	Survey	Data collection from GSO (general statistics office)	Total factories
1	Hanoi	300	11.123	11.423
2	Hung Yen	4	301	305
3	Bac Ninh	4	4.597	4.601
4	Vinh Phuc	8	30	38
5	Hai Duong	6	189	195
	Total	322	16,240	16,562

### 2.2.2 Emission Calculation Method Based on Emission Factor and Activity Factor

Industrial emissions in this study are mainly emissions from the chimneys of industrial plants. Some US and European countries also add criteria on industry groups (with a list of industries classified as point source) and emission levels (scale of production) to determine point sources. Based on the theoretical basis of point sources and inventory of point sources from previous studies and the guiding documents of the Ministry of Natural Resources and Environment, the research team evaluated and selected the types of Calculation source for point distribution, including emissions from the production process, fuel consumption and solid waste for businesses of all different industries in the study area.

Emissions of ONKK substances in an industrial production plant are calculated with 2 parts, which are emissions from burning fuel and emissions from the production process.

Formula for calculating emissions from burning fuel:

$$E_{f,i} = AR_{f,i} \times EF_{f,i} \times (1-ER/100) \quad (1)$$

In there:

- $E_{f,i}$  : Emission load of fuel i, kg/year;  $EF_{f,i}$  : Emission coefficient of fuel i used, kg/ton
- $AR_{f,i}$  : Amount of fuel i used (tons/year); ER: Efficiency of air pollution treatment system (%)

The formula for calculating emissions from the production process:

$$E_i = AR_i \times EF_i \quad (2)$$

In there:

- $E_i$ : Emission load of industry i, kg/year;  $EF_i$ : Industry emission factor i, kg/ton;  $AR_i$ : Production output of industry i (ton/year);

In this study, the available emission factors will be selected according to the main sources: US-EPA AP42 gas emission factor; EMEP/EEA Emission Inventory Guidelines; European Union- CORINAIR; IPCC 2006.

- Some emission coefficients developed by studies in Vietnam.

According to the presented calculation method, this study calculates emissions of ONKK based on emission coefficients. This section summarizes the emission factors of ONKK from the European Environmental Protection Agency (EMEP/EEA air pollutant emission inventory guidebook 2019) and the GHG inventory guide. Emission Inventory Manual of the Asian Institute of Technology.

TABLE 2 EMISSION COEFFICIENT OF ONKK SUBSTANCES FROM FUEL USE

Type of fuel	NO <sub>x</sub>	CO	SO <sub>x</sub>	NM VOC	TSP	PM <sub>2.5</sub>	CH <sub>4</sub>
Biomass (g/ton)	1,419.6	8.89	171.6	4.68	2,340	2.18	468
DO (g/liter)	18.90	2.43	1.73	0.92	0.7 4	0.7 4	0.11
LPG (g/liter)	1.6 9	0.66	0.0 2	0.52	0.0 2	0.01 8	0.02
Coal (g/ton)	5,070.46	27,286.68	26,378.1	2,602.64	3,634.32	3,165.37	293.09
CNG (g/m 3 )	2.85	1.1 2	0.0 3	0.8855	0.03	0.03	0.0 4
Domestic solid waste (kg/ton)	1.8	0.7	1.7	0.02	18.3	-	-
Medical solid waste (kg/ton)	2.5	0.1 3	0.07	7.4	2.33	-	-
Industrial solid waste (kg/ton)	2.5	0.1 3	0.07	7.4	-	-	-

Source: EMEP-EEA 2019, AIT 2012

### 2.2.3 Modeling Methods: TAPM and AERMOD

#### a. Meteorological Model

The Air Pollution Model (TAPM) was developed by the Commonwealth Scientific and Industrial Research Organization - Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia. TAPM is a three-dimensional Eulerian meteorological model for simulating meteorology. The model is non-hydrostatic and anelastic using terrain following grid with finite volume discretization. The TAPM model was adopted as the input for the AERMOD model. The model management characteristics data on the surface and on different levels of height, allows the calculation of atmospheric. The meteorology file consists of the following two types: surface met data file (\*.sfc) contains the 1-hour observed data including wind direction, wind speed, humidity, atmospheric pressure, precipitation, cloud cover, solar radiation; and the upper air data file (\*.pfl) including similar parameter but in many levels of height.

There are four domains from D1 to D4 for nesting one way technique simulation, including: (i) D1 is 800km x 800 km (with 40 x 40 grids and the grid resolution was 20km), the outer most domain D1 characterizing the North of Vietnam; (ii) D2 is 400 km x 400 km (with 40 x 40 grids and the grid resolution was 10km), the wider domain D2 characterizing Mekong Delta; (iii) D3 is 300 km x 300 km (with 40 x 40 grids and the grid resolution was 5km), the domain D3 characterizing Hanoi and some neighboring provinces; (iv) and D4 is 140km x 140km (with 71 x 71 grids and the grid resolution was 2km), the subdomain D4 characterizing the main part of study domain. In which the three outer domains

(D1, D2, D3) were meteorological simulation only and the inner domain (D4) was both meteorological and chemical simulation. The size of the inner-most domain (D4) was set to be the same as the emission inventory domain. The meteorological grids must be greater or equal to the emission grids; therefore, the emission inventory domain was set 140 km by 140 km with 71x71 grids and the grid resolution was 2km x 2km.

TABLE 3 EMISSION COEFFICIENT OF ONKK SUBSTANCES FROM THE PRODUCTION PROCESS

Branch	Technology	NO <sub>x</sub>	CO	SO <sub>x</sub>	NMVOC	TSP	PM <sub>2.5</sub>	CH <sub>4</sub>
Manufacturing cement (kg/ton of product)	Wet oven technology (uncontrolled)	-	-	0.3	-	-	4.64	-
	Wet furnace technology treated with ESP technology	-	-	0.3	-	-	0.25	-
	Dry kiln technology treated with fabric filter technology	-	-	0.3	-	-	0.045	-
Brick production (kg/ton of product)	Crushing and screening technology (uncontrolled)	-	-	-	-	-	-	-
	Furnace (uncontrolled)	1.46	4.2	-	-	-	0.44	-
Metal production (kg/ton of product)	Cast iron production	0.076	1.34	3	0.12	-	0.04	-
	Aluminum production	2.15	135	15.1	0.02	-	1.48	-
	Copper production	-	-	2,120	0.03	-	193	-
	Lead production	-	-	320	-	-	3.6	-
	Zinc production	-	-	1,000	-	-	3.6	-
Drinks (kg/100 liters of product)	Beer	-	-	-	0.035	-	-	-
	Alcohol	-	-	-	0.035	-	-	-
Food (kg/ton of product)	Meat, fish and poultry (cooked only)	-	-	-	0.18 – 0.3	-	-	-
	Sugar	-	-	-	10	-	-	-
	Cakes, cookies and breakfast cereals	-	-	-	1	-	-	-
	Bread	-	-	-	4.5	-	-	-
	Fodder	-	-	-	1	-	-	-
	Coffee roasting	-	-	-	0.55	-	-	-

Source: EMEP-EEA 2019, AIT 2012

## b. Air Quality Model

The AERMOD Model - The AMS/EPA Regulatory Model (AERMOD) is designed to support the US Environmental Protection Agency (EPA) management program. The model consists of three components: AERMOD (AERMIC Scattering Model), AERMOD (AERMOD Terrain Tool), and AERMOD (AERMOD Meteorological Tool). Since 1991, the AERMOD model has been developed by the Meteorological Agency and the US Environmental Protection Agency (US EPA). A team of scientists (AERMIC) has teamed up to build the AERMOD model. AERMOD was officially used on December 9, 2005, after 14 years of research and development. AERMOD will produce simulation results in the form of 2-dimensional, three-dimensional images and and export them through Google Earth, making it easy for users to see the effects of emissions to the survey area. The grids domain was set 459 km by 459 km with 153 cells x 153 cells and the grid resolution was 3.0 km x 3.0 km, covering the study areas.

## c. Model Evaluation

Similar to other models, TAPM and AERMOD models also need to be evaluated before using. This approach was used by comparing the observations from the field with the modeled data. In which meteorological data at Vinh Yen station was used to assess the TAPM and AERMOD model, respectively. More specifically, statistical parameters including Pearson correlation coefficient (R) between observed (O) and predicted (P) values, mean value, standard deviation, minimum value (min), and maximum value (max) were used in this study. It is imperative to evaluate the air dispersion model with observation data before using the simulated results, to check the input data and options for the research area and the uncertainty of the model. The Mean Normalized Bias Error (MNBE) was used to evaluate model performance. The Results of model evaluation for TAPM model has R2 of 0.73 and for AERMOD model has MNBE of -11.65% (-12.62% - 10.67%). These values show that both TAPM and AERMOD model is qualified for simulation.

### 3 RESULTS AND DISCUSSION

#### 3.1 Calculation Results of Total Emissions of Air Pollutants from Industrial Activities

The study calculated the emissions of ONKK substances, the calculated results from this study were compared with the results of the industrial emission inventory of Ho Chi Minh city (2019) and Can Tho city (2016) by Ho Quoc Bang et al (Table 4). Thereby, it shows that Vinh Phuc's industry emits at a higher level than some other provinces/cities, pollutants, especially  $PM_{2.5}$ ,  $PM_{10}$ ,  $SO_x$  are higher than Ho Chi Minh city due to industrial activities in Ho Chi Minh city uses a lot of liquefied petroleum gas, while industrial activities in Vinh Phuc according to survey data, most businesses use wood as raw materials and use coal as the main fuel.

TABLE 4 EVALUATION OF THE CALCULATION RESULTS OF EMISSIONS OF ONKK FROM INDUSTRIAL ACTIVITIES OF HANOI CITY, VINH PHUC, HAI DUONG, HUNG YEN, BẮC NINH PROVINCES COMPARED TO HO CHI MINH CITY AND CAN THO CITY

Unit: tons/year

Local	NO <sub>x</sub>	CO	SO <sub>x</sub>	NMVOC	TSP	PM <sub>2.5</sub>
Ho Chi Minh	4,395.1	27,194.1	8,689.5	11,135.7	-	2,021.9
Can Tho	2,495	16,441	2,786	8,648	-	-
Hanoi	1,781.3	14,797.6	6,047.7	9,341.4	8,318.8	2,743.9
Bac Ninh	122.6	67.4	9.9	-	1,166.9	4.6
Hai Duong	126.4	6.6	6.8	-	22.2	84.3
hung Yen	122.7	934.9	1,115.9	-	31.8	23
Vinh Phuc	138.2	1,683.9	57,656.1	-	108,508	108,515

#### 3.2. Simulation of the Impact of Potential Industrial Emissions on the Air Quality of Hanoi City

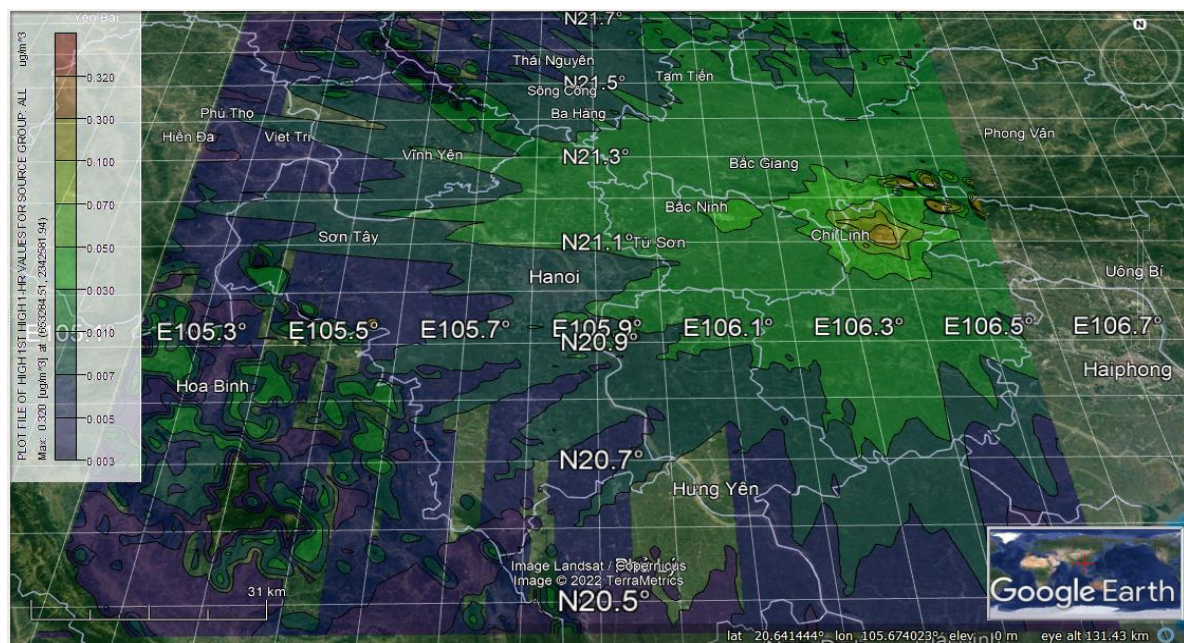


FIGURE 2 SIMULATED RESULTS OF 1 HOUR FOR  $PM_{2.5}$  PARAMETERS ARE OUTPUT VIA GOOGLE EARTH.

Simulation results of air pollution for potential emission sources around Hanoi city has the highest concentration in 1 hour (Figure 2), 24 hours and annual average of  $PM_{2.5}$  respectively 0.32; 0.023; 0.003 ( $\mu g/m^3$ ), the simulation results are very low and occur only in some hours of the year. Therefore, the emission contribution of the surrounding provinces to Hanoi city is quite small.

Simulated results of air pollution for potential emission sources around Hanoi city has the highest concentration at 1



hour (Figure 3), 24 hours and the annual mean of PM<sub>10</sub> is 1.03 respectively; 0.074; 0.098 (µg/m<sup>3</sup>), the Simulated results are very low and only occur in some hours of the year. Therefore, the emission contribution of the surrounding provinces to Hanoi city is quite small.

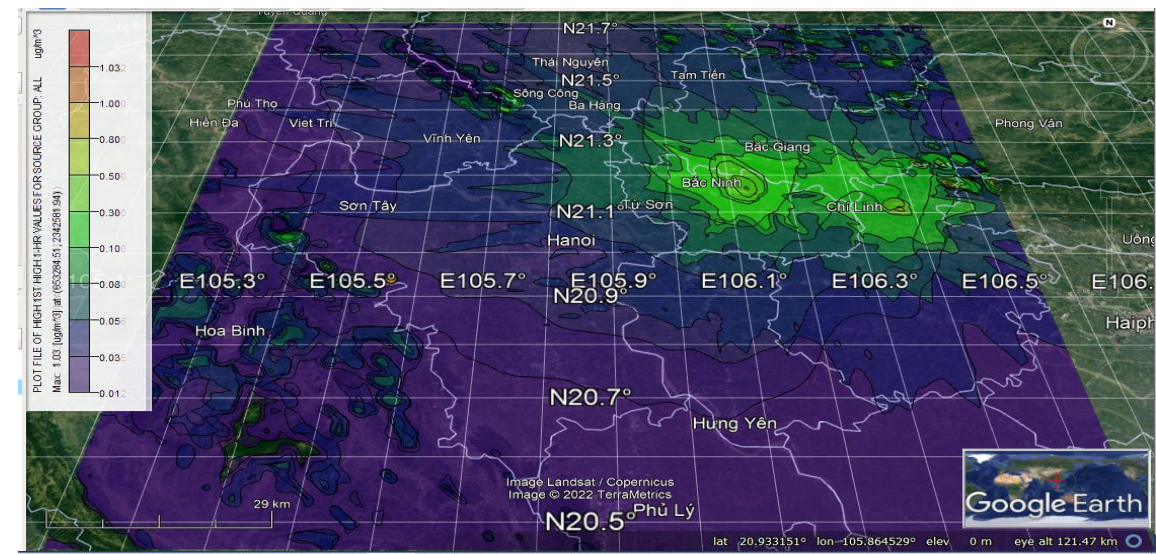


FIGURE 3 SIMULATED RESULTS OF 1 HOUR FOR PM10 PARAMETERS ARE OUTPUT VIA GOOGLE EARTH.

Simulated results of air pollution for potential emission sources around Hanoi city has the highest concentration at 1 hour (Figure 4), 24 hours and annual mean of NO<sub>x</sub> respectively 7.94;1.02; 0.222 (µg/m<sup>3</sup>), the Simulated results are very low and only occur in some hours of the year. Therefore, the emission contribution of the surrounding provinces to Hanoi city is quite small.

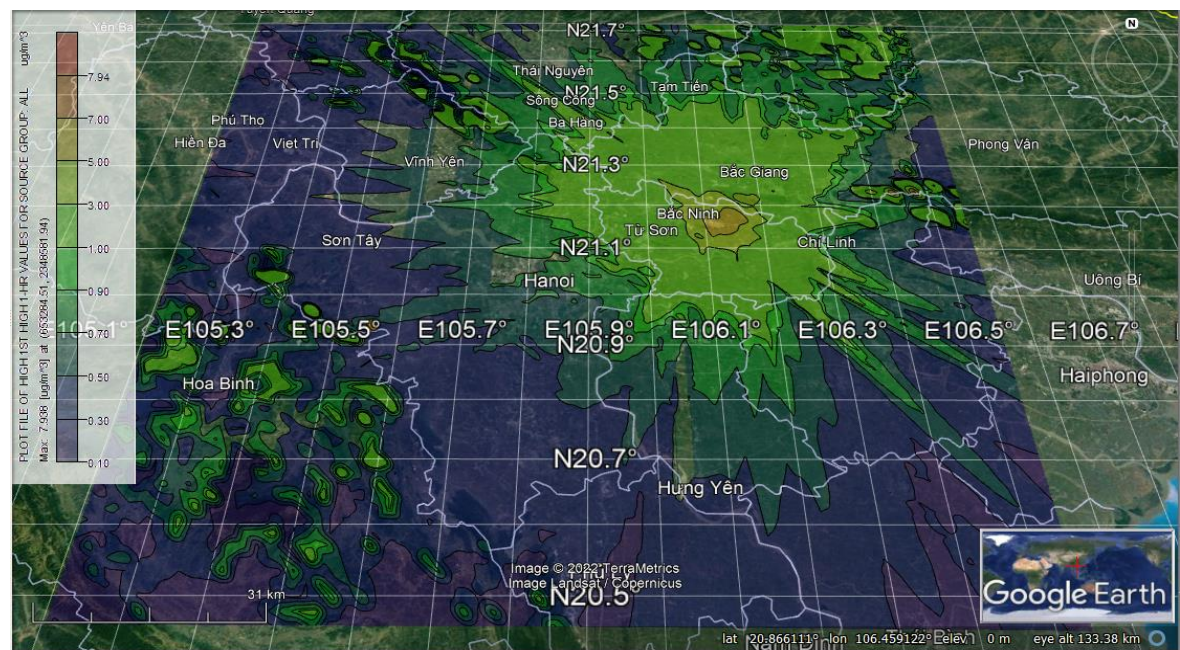


FIGURE 4 SIMULATED RESULTS OF 1 HOUR (G) FOR NOX PARAMETER ARE OUTPUT VIA GOOGLE EARTH.

Simulated results of air pollution for potential emission sources around Hanoi city has the highest concentration at 8 hours (figure 5), 24 hours of CO 27.616 respectively; 8.89 (µg/m<sup>3</sup>), the Simulated results are very low and occur only in some hours of the year. Therefore, the emission contribution of the surrounding provinces to Hanoi city is quite small.



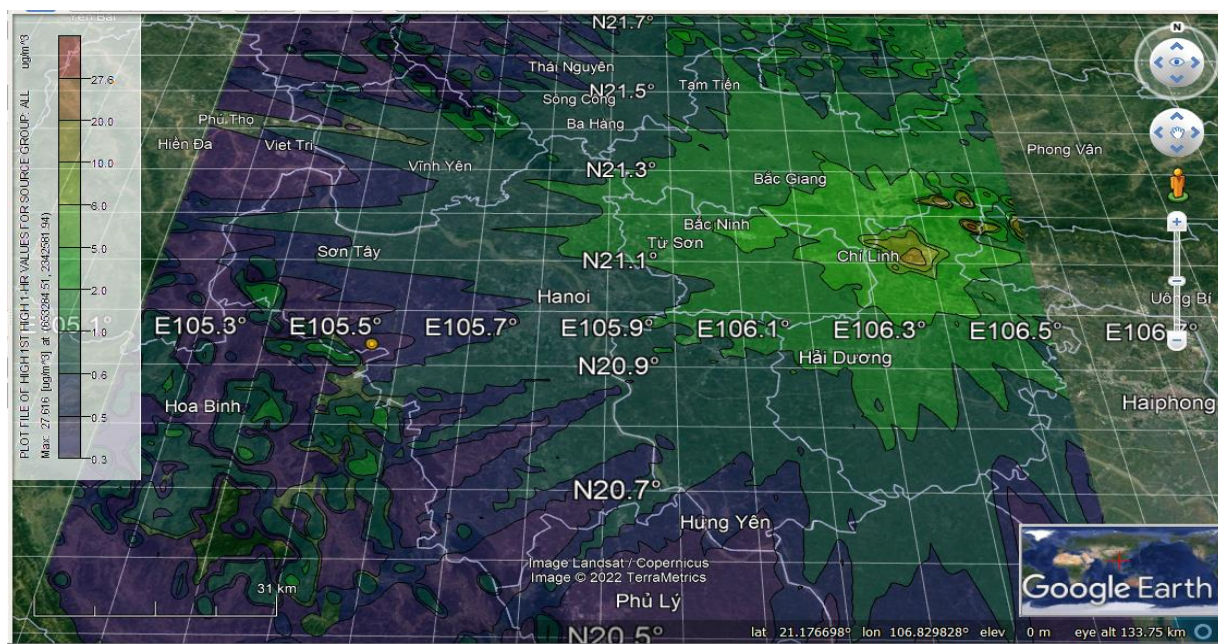


FIGURE 5 SIMULATED RESULTS FOR 8 HOURS FOR CO PARAMETER OUTPUT VIA GOOGLE EARTH.

Simulated results of air pollution for potential emission sources around Hanoi city has the highest concentration at 1 hour (Figure 6), 24 hours and the annual mean of  $\text{SO}_x$  4.005 respectively; 0.288; 0.038 ( $\mu\text{g}/\text{m}^3$ ), the Simulated results are very low and occur only some hours of the year. Therefore, the emission contribution of the surrounding provinces to Hanoi city is quite small.

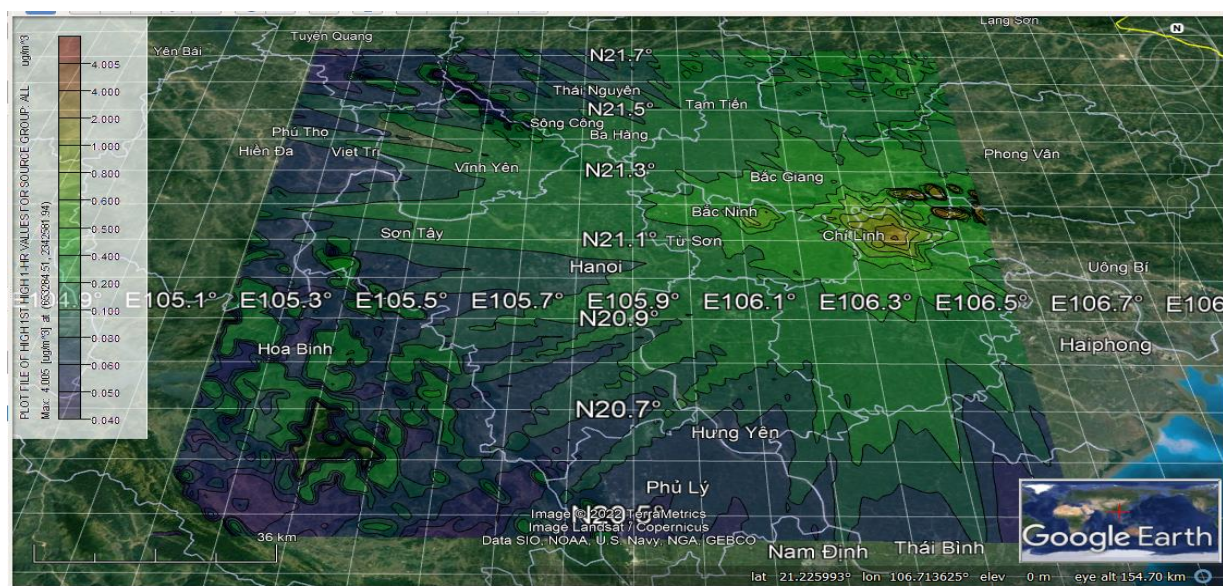


FIGURE 6. SIMULATED RESULTS OF 1 HOUR FOR  $\text{SO}_x$  PARAMETER OUTPUT VIA GOOGLE EARTH.

Through simulated results of the current status of air quality in 4 provinces of Hung Yen, Vinh Phuc, Bac Ninh and Hai Duong, pollutants  $\text{NO}_x$ , CO,  $\text{SO}_2$ ,  $\text{PM}_{2.5}$ ,  $\text{PM}_{10}$  for the above point sources show that these substances are all within the permissible limits of environmental standards.

## 4 CONCLUSIONS AND RECOMMENDATIONS

This is the first study on inventory of potential emissions in the Northern Key Economic region and the application of the TAPM meteorological model combined with the AERMOD model to simulate the spread of air pollution for 4 provinces. Hung Yen, Hai Duong, Vinh Phuc and Bac Ninh to Hanoi city. Calculation results of air pollutants emissions from industrial activities of Hung Yen, Hai Duong, Vinh Phuc and Bac Ninh provinces for  $\text{NO}_x$ , CO,  $\text{SO}_2$ ,



PM<sub>10</sub>, PM<sub>2.5</sub> times turns are 509.81; 2,692.76; 58,788.62; 109,728.85; 108,626.89 (tons/year). In which, Vinh Yen city, Tam Dao district and Binh Xuyen district, Vinh Phuc province are the localities that contribute the highest number of industrial emissions. This is because in these places there are high emissions of wood and brick production leading to high total pollutant emissions.

Districts such as Son Tay town, Nam Tu Liem district, Ba Dinh, Hoan Kiem, Dong Anh are the areas that contribute the highest emissions; It is particularly noteworthy that Son Tay town accounts for 14-22% of the total emissions of each substance. The study also calculates and shows that some industries producing products such as paper and construction bricks have very high emission levels compared to other industries. Calculation results of emissions of air pollutants from industrial activities for NO<sub>x</sub>, CO, SO<sub>2</sub>, PM<sub>10</sub>, PM<sub>2.5</sub> are 1,781.3 respectively; 14,797.6; 6,047.7; 9,341.84; 8,318.8 and 2,743.9 (ton/year). In which, CO, PM<sub>10</sub>, PM<sub>2.5</sub> arising from industrial processes are mainly compared to the total emissions due to fuel consumption and emissions due to solid waste, because the contribution is 14,591.3 respectively; 8,270.5 and 2,720.8 of the total emissions of these substances.

From the results of detailed emissions inventory for the city's industry. Hanoi and neighboring provinces have calculated for the most polluted industries, factories and districts in the city. Although the air pollutants in the potential emission sources make a relatively small contribution to the air quality in Hanoi city, but with the current industrial development speed of the provinces/cities, environmental issues will be a concern not only in the project construction area but also in the surrounding area. In order to perform well the state management of environmental protection for industrial production activities in the provinces/cities in the coming time, it is necessary to synchronously implement solutions on management and technology to control the air quality of the emission sources to reach the threshold of environmental regulations prescribed for air quality, in order to limit the generation of polluting points, and protect the health of the workers working in industrial zones and residential areas living around the industrial zones.

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## AUTHORS



<sup>1</sup>**Bang Quoc Ho** is currently a director of Air Pollution and Climate Change Research Center - Institute of Environment & Resources (IER) - Vietnam National University, Ho Chi Minh City (VNU-HCM) and a vice director of Academic Affairs Department /VNU-HCM). He got the master and PhD in environmental sciences at EPFL, Switzerland, he works on air and GHG emission inventory, air pollution and climate change.



<sup>2</sup>**Khue Vu** has a master degree of environmental management. She is now doing PhD at Czech Globe. She has been worked in Air pollution and Climate change Research Center - Institute for Environment and Resources – VNU-HCMC, Vietnam. She has experience with air quality modeling and emission inventory. Her current research involves air quality modeling, air emission inventory and climate change.



<sup>3</sup>**Tam Nguyen** has a master degree of environmental management. He has been worked in Air pollution and Climate change Research Center - Institute for Environment and Resources – VNU-HCMC, Vietnam. His current research involves air quality modeling, air emission inventory and climate change.



<sup>4</sup>**Cau Le** is currently Director of Center for Environmental Research, Vietnam Institute of Meteorology, Hydrology and Climate Change. He earned Master's Degree in Environmental and Technology from Asian Institute of Technology (AIT), and PhD in Socio-Cultural Environmental Studies from The University of Tokyo. His recent research includes emission inventory, GHG emission mitigation in waste sector.