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Simulation of thermal power plant source contribution to ambient air concentration in Cam Pha City, Quang Ninh province using AERMOD dispersion model

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ABSTRACT

Cam Pha, the home of three major thermal power plants including Cam Pha, Mong Duong I and Mong Duong II, is one of the most important industrial cities in the North of Vietnam. Air pollution due to stacks emission is the biggest problem threatening Cam Pha City's sustainable development. In this study, the AERMOD modeling system was used to evaluate the impact of the stack emission by the thermal power plants on the ambient atmospheric environment. The maximum 1-HR, 24-HR, 99th percentile and annual average concentrations of TSP, SO_2 and NO_2 were simulated within the 40x40 km domain of 100x100 m grid spacing with the hourly meteorological data taken from 2018 to 2020. Air dispersion simulation is performed on the observed background gas concentration of the everyday environment. Hourly emission data of 10 primary stack sources of 3 factory groups were used as input data. The simulated spatial distribution of gases indicates the strong fluence of the mountainous topography on the dispersion of stack emission. Results also revealed that the maximum short-term stack emission at ground-level concentrations of SO_2 and NO_2 are much higher than the national standard, thus raising the risk of severe pollution. TSP pollution is less severe than SO_2 and NO_2 but still at a dangerous level. Since Cam Pha locates by the East Sea with the prevailing wind is heading northeast and east directions. The annual average concentrations of these pollutants indicate that the high terrain areas at the south and northwest of Cam Pha City, which block the flow of the stack emission, are the most affected regions by exhausted gases from industrial stacks.

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1. Introduction

Quang Ninh province is one of the largest coal mining regions in the country that plays an important role in the country's development. Cam Pha, one of the four cities in Quang Ninh, locates the largest number of thermal power plants in Quang Ninh province with three large thermal power plants, including Cam Pha thermal power plant, Mong Duong 1 and Mong Duong 2 thermal power plants. Coal-fired power plants are emitting huge amounts of exhaust gases and ash from the burning of fossil fuels. The exhaust stacks of these thermal power plants emit at 155÷208 m in height. With such high altitude, along with wind speed and surrounding terrain, smoke and dust from fuel combustion can be dispersed from the stack tip, affecting the vast surrounding areas. Air pollution is a major problem in Cam Pha province, causing serious problems in society. The situation directly threatens the sustainable socio-economic condition, the existence and the development of the present and future generations. According to the statistics, the number of people suffering from respiratory diseases in Quang Ninh has accounted for 80% of the whole country. The issue of identifying and controlling the current status of pollution sources is being put on priority. In-depth studies on sources of environmental pollution from industrial stacks in Cam Pha are expected to help the management agencies to better control the situation (Figure 1).

The combination of air pollution monitoring and atmospheric dispersion models is proven to be a good and effective tool for environmental management (Mazzeo and Venegas, 2008), i.e. the Industrial Source Complex Short Term model (ISCST3), CALPUFF and AERMOD. Since 2006, the AERMOD model developed by US EPA has been considered the state-of-the-art evaluation tool for environmental impact assessment for many air pollutants. AERMOD has been fully promulgated as a replacement for ISC3 thanks to its effective concepts about flow and dispersion in complex terrain. In this study, we adopted the AERMOD dispersion model to simulate the impact of thermal power plants on the ambient air quality at the ground level of Cam Pha City. This finding will contribute to the prioritization of appropriate mitigation measures in controlling the emission of

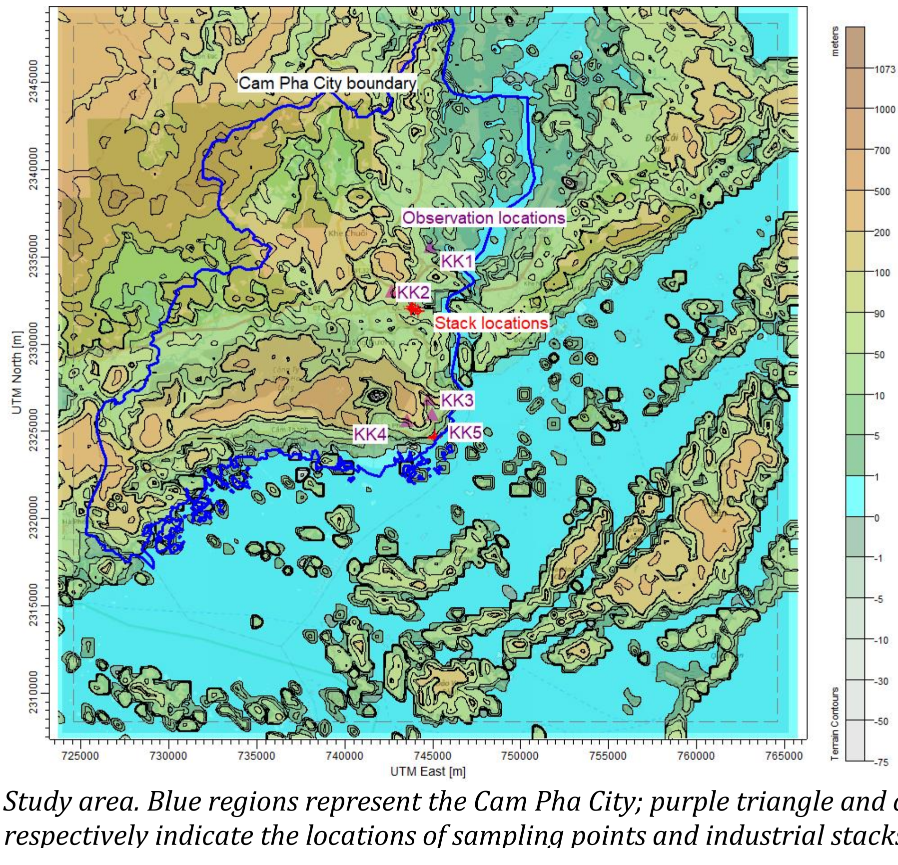

Figure 1. Study area. Blue regions represent the Cam Pha City; purple triangle and cross mark respectively indicate the locations of sampling points and industrial stacks.

each source as well as demonstrate the application of the air dispersion model.

2. Materials and methods

2.1. AERMOD model

AERMOD, the US. EPA regulatory dispersion model based on the indications of AERMIC (American Meteorological Society / Environmental Protection Agency Regulatory Model Improvement Committee) that outlined a new basis for steady-state air quality models to be used for regulatory purposes. AERMOD has been widely used for environmental management purposes (Silverman et al., 2007; Suadee, 2008; Huertas et al., 2012). The AERMOD modeling system is composed of three different modules: The main atmospheric dispersion module (also called the AERMOD module); The terrain processor AERMAP that process complicated satellite data to evaluate the topography height for each receptor; The AERMET processor which is used to prepare the meteorological boundary conditions for the desperation model; and finally, the AERMAP module that can be used to construct the geophysical parameters (surface roughness, albedo, Bowen ratio) to be feed in AERMET. The AERMOD model is recommended for short-range dispersion modeling at a distance up to 50km from the emission source (Seangkiatiyuth et al., 2011; Krzyzanowski, 2011). This study used AERMOD model version 21112 under the AERMOD View product version 10.01 by Lakes Environmental Software.

2.2. Emission data

Hourly emission data from Jan-2020 to Sep-2022 were obtained from the Department of Natural Resources and Environment (DONRE) database at Quang Ninh City. These data were recorded from the automatic data monitoring system at each industrial chimney of each factory during its operation.

Since the Cam Pha City has three major industrial emission sources, simulation for exhausting gases from the chimneys targeted 10 stacks that were classified into three company groups: (1) The Cam Pha thermal power plant, (2) Mong Duong I thermal power plant, (3) Mong Duong II thermal power plant. The emission characteristic of each stack is summarized in Table 1.

Table 1. Characteristic of emission sources.

Thermal Power Plan	Stack	Terrain Height (m)	Stack height (m)	Stack Diameter (m)	Stack exit velocity (m/s)	Temperature (°K)	Emission rate (g/s)		
							TSP	NO_x	SO_2
Cam Pha	1	3	155	2.5	6.63	406.98	16.22	51.59	69.18
	2	3	155	2.5	7.72	392.82	19.56	148.38	68.61
	3	3	155	2.5	11.58	406.48	26.04	104.27	83.73
	4	3	155	2.5	6.10	413.53	14.02	58.20	30.36
Mong Duong I	5	7	200	2.3	10.65	452.59	40.63	160.10	57.95
	6	7	200	2.3	23.00	446.83	133.99	75.97	118.28
	7	7	200	2.3	12.10	400.21	16.49	35.60	65.11
Mong Duong II	8	7	200	2.3	12.99	398.52	15.34	64.81	108.33
	9	7	208	2.5	10.07	413.85	71.01	470.85	165.38
	10	7	208	2.5	41.03	404.12	262.83	500.59	794.46

- Stack exit velocity and emission rate are indicated at 99^{th} percentile region
- Data provided by the automatic monitoring system installed at each stack and managed by the Quang Ninh local DONRE

2.3. Air quality monitored data

For validation of the model, hourly average air quality data were collected at 5 locations for consecutive five days from 16-Jul 2022 to 20 Jul 2022. We used nighttime emission data (23'00 to 3'00) for the validation process to minimize the effect of other emission sources effection the surrounding ambient air quality, such as transportation or other municipal activities. Total suspended particulate (TSP), NO_x and SO_2 were considered in this study.

2.4. Meteorology data

We used the ERA5 atmospheric, land and oceanic climate variables for surface meteorological data. ERA5 data cover the Earth on a 30km grid and resolve the atmosphere from the ground up to 80 km height using 137 vertical levels. Upper air meteorological condition, i..e. wind speed (Figure 2), was taken from the hourly recorded radiosonde data at Noibai International Airport.

2.5. Terrain and land use data

The digital elevation model data used in AERMOD was extracted from 1 arc-second resolution SRTM (Shutter Radar Topography Mission) topographic data (~30 m resolution) produced by NASA (National Aeronautics and Space Administration) in collaboration with NGA (Geospatial-Intelligence Agency). The elevation data on the computed domain is bilinear interpolation to match the spatial resolution to the receptors grid using AERMAP.

Land cover data at 30 m resolution was prepared using the combination with 100m resolution Global Land Cover (GLC) land cover data and Google Maps satellite image data. The Global Land Cover Map is a data product developed by Copernicus' Land Monitoring Core Service (LMCS) - Europe's leading program for Earth observation.

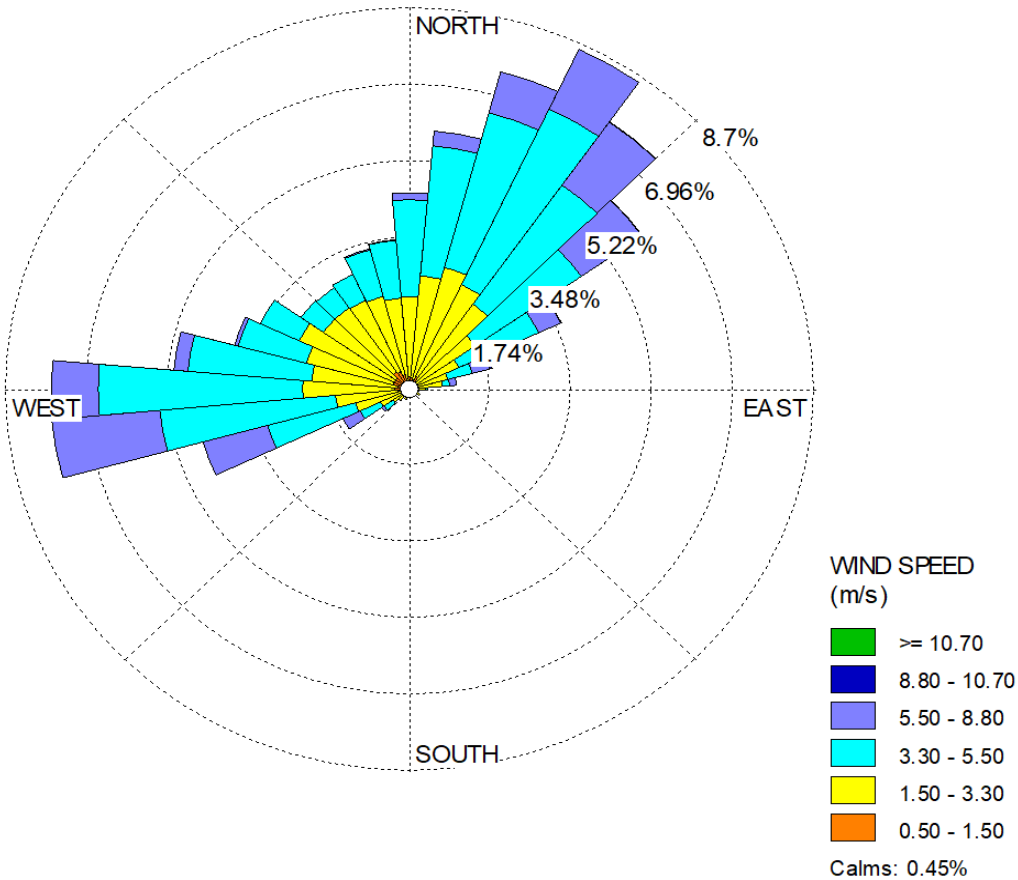

Figure 2. Wind rose of Quang Ninh province from 1/1/2018 to 31/12/2020.

2.6. Experiment setup

Data periods read from meteorological data files were started from the 1st hour on 1 Jan 2018 to the 24th hour on 31 Dec 2020, a total of 26.403 timesteps. The simulation domain was configured for a 40x40 km region centred by Cam Pha City and covered by the Cartesian receptor grid made up of 40.401 nodes of 100x100 m resolution. In this study, NO_x is assumed to be fully converted to NO_2 under simulation.

3. Results and Discussion

3.1. Validation of AERMOD dispersion model

The model's performance was evaluated by comparing simulated with monitored data within the study domain in 5 different locations, which are 2÷4 km from the Cam Pha stack behind the prevailing wind direction. The natural air quality of the selected locations is less affected by industrial and domestic emission sources to avoid cross-contamination. Statistical analysis was employed to determine the model's performance in predicting the hourly average concentrations and reproducing the spatial distribution of the pollutants. Figure 3 compares the 5 day averaged simulated hourly data with observation data for TSP, NO_x and SO_2, respectively. In all locations, the AERMOD model consistently underestimates observation with RMSEs varying from 16.02÷25.46 μg/m3. Since Cam Pha city is an industrial and populated city, it is impossible to find a location that represents the natural environment of the area unaffected by anthropogenic emissions. Stacks emissions are simulated by ignoring the background ambient concentration, so the simulation results are lower than the reality is understandable. Besides, the high Pearson correlation coefficients found in all cases, from 0.74÷0.94, have indicated the excellent reproducibility of the AERMOD model in capturing the spatial distribution of pollutants. Regardless of the limitation in finding a suitable observation site for validation, the consistent results of the AERMOD model show the excellent applicability of using AERMOD for further investigation of stack-born TSP, NO_2 and SO_2 in Cam Pha City.

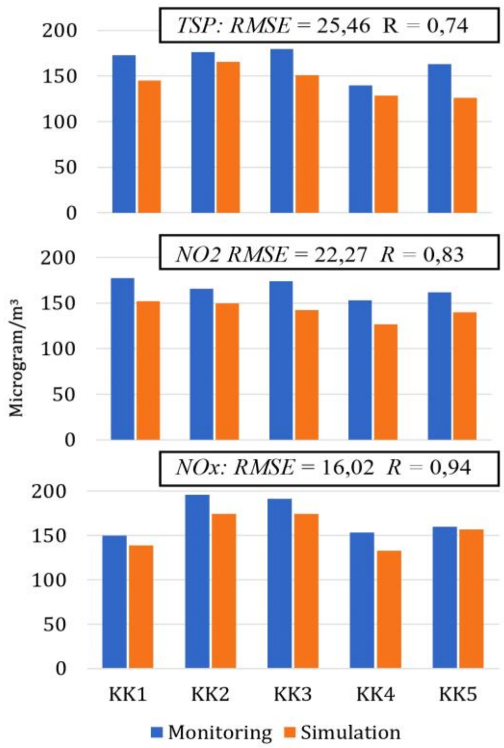

Figure 3. Comparation between the simulated and observed concentrations of pollutants.

3.2. Contributions of industrial stack emission to the ambient air quality of Cam Pha City

3.2.1. Extreme short-term emission scenarios

The extreme emission scenarios of TSP, NO_2 and SO_2 from the stacks in Cam Pha City in Figure 4 represent the highest hourly emission during the simulation period. Under worse scenarios, the concentration of all pollutants is much higher than the maximum allowed national standard threshold (Table 2). The maximum value of TPS, NO_2 and SO_2 are consecutively 2.8, 8.1 and 14.2 times exceed limitations. However, the regions with the highest simulated concentration of pollutants are very small, several pixel which are difficult to distinguish from the surrounding environment. Commonly high concentrations reach about 70÷80% of the maximum detected value. NO_2 pollution is forecasted to be more severe than SO_2 and TSP. At a distance of over 20 km from the centre of Cam Pha city, the NO_x concentration in the

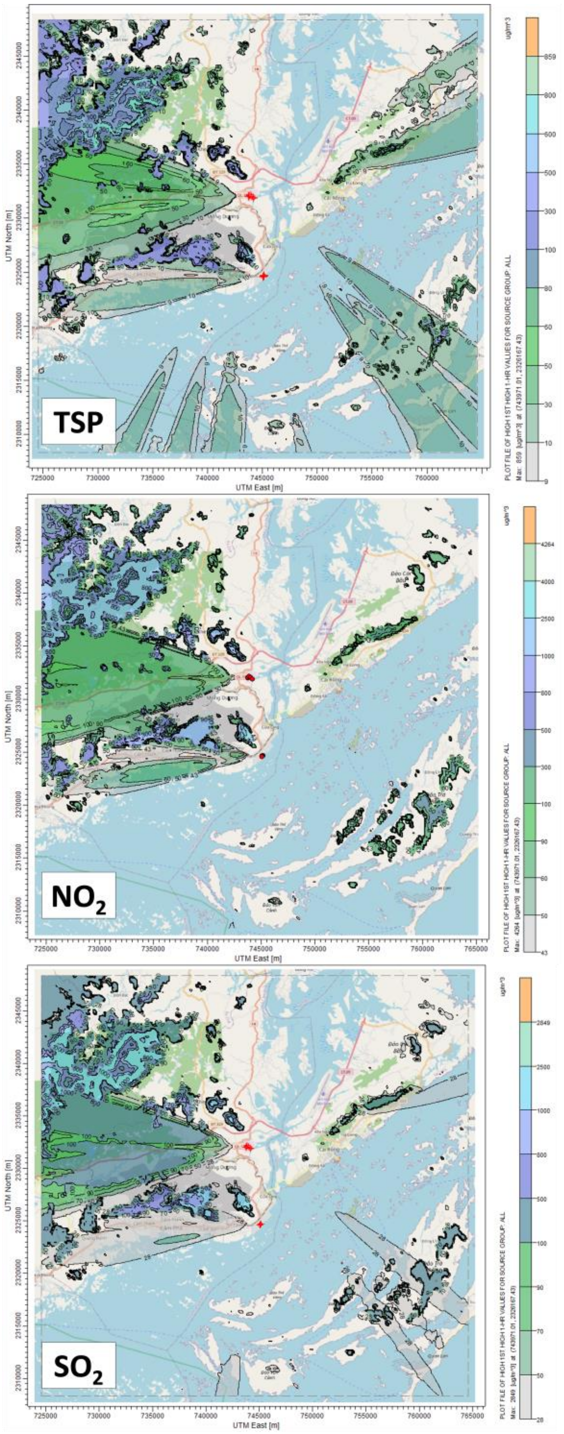

Figure 4. The worst 1-HR emission scenarios by TSP, NO_2 and SO_2.

highest 1-HR emission scenario ranges from 100÷500 μg/m^3, exceeding the national standard of 200 μg/m^3. Simulation output for the maximum 24-HR emission (result not shown) also shows a similar affected location to the 1HR scenarios. The lower concentration of pollutants found in the 24-HR scenarios has resulted from the variation in daily meteorological conditions and the production period of each factory.

Table 2. National Technical Regulation on Ambient Air Quality - QCVN 05:2013 MONRE (μg/m^3).

Pollutant	1-HR	24-Hr	Annual
TSP	300	200	100
NO_2	200	100	40
SO_2	350	125	50

The contribution of stack emission to the risk of environmental pollution is further investigated by calculating the 99th percentile region of 1-HR and 24-HR simulation for the baseline period. At the very low probability of 1%, AERMOD 1-HR simulation output indicates the TSP concentration may reach up to 277 μg/m^3, very close to the limitation (Figure 5); both SO_2 and NO_2 maximum concentration, 800 μg/m^3 and 1.172 μg/m^3, consecutively exceed the limit of 350 μg/m^3 and 200 μg/m^3. AERMOD output suggests the high risk of environmental pollution due to stack emissions, especially SO_2 and NO_2. The same conclusion is also withdrawn from the 24-HR simulation at the 99th percentile region.

3.2.2. Dispersion of pollutants in Cam Pha city

The annual average simulation results examine the spatial distribution of pollutants (Figure 6, for example). Averaged for three years of simulation, although the stack-born concentrations of TSP and SO_2 in the ambient environment are still lower than the limitation threshold, but still at very high levels. Besides, NO_x has surpassed the limit of the environment even though the cumulative effects of other emission anthropogenic sources have not been taken into account. The regions over the ocean are not affected by stack emission. However, the hilly objects of the islands seem to be affected by the exhaust gas flow. The areas near the stack locations are less affected by the exhaust gas than the remote areas, thanks to the high altitudes of the stack tip. The exhaust smoke has to travel a long distance before settling on the ground. The areas affected the most by thermal power plants are located in the

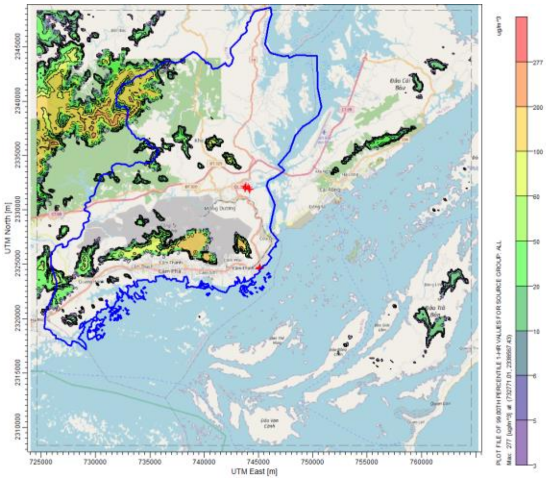

Figure 5. TSP concentration of 1-HR emission at 99th percentile region.

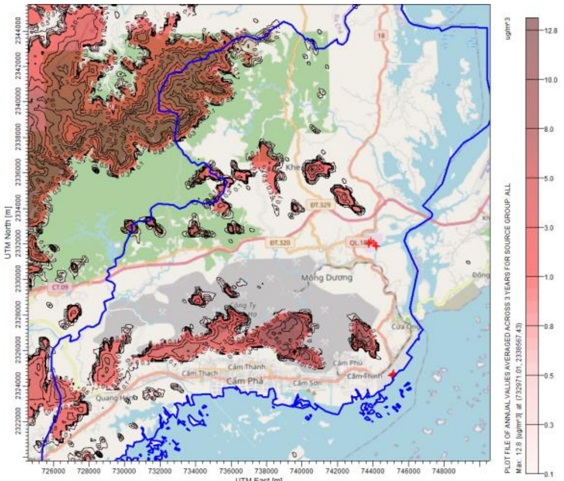

Figure 6. Annual average of TSP concentration.

mountainous/hilly terrain in the south and northwest of the research area: Cam Pha City Center, Quang Hanh and Cam Son. The AERMOD model considers an assumption of no cross-contamination by other air pollution sources. In reality, the situation may be much worse due to the cumulative effect of multiple air emission sources.

In general, topography strongly influences the distribution of exhausting gases in the atmosphere, as illustrated in Figure 7. The mountainous areas or high terrain will prevent the propagation of exhaust gas flows from the landfill, making the gas streams unable to pass, but moving to the sides and creating areas of high gas concentration, such as the North-Western mountainous region.

4. Conclusion

Environmental pollution from the stack emission of thermal power plants in Cam Pha is one of the top concerns of the authorities. In this study, the AERMOD model was used to evaluate the influence of stack-born pollutants on the ambient air environment, namely TSP, NO_2 and SO_2 gases. The observed 5-day hourly observation data for ambient air quality and stack emission was used to validate the model. The AERMOD simulation output for the validate period captured the distribution and concentration of pollutants well.

AERMOD simulation with 2018 to 2020 meteorological data has shown the thermal power plant's high risk of air pollution. Under the short-term emission scenario, all pollutants are found

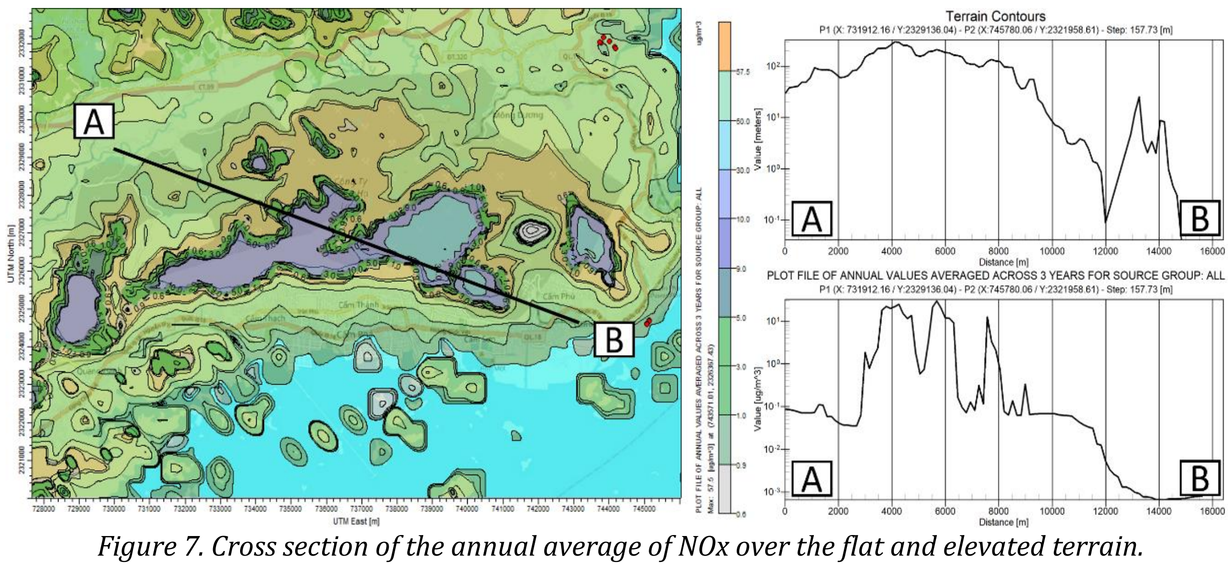

Figure 7. Cross section of the annual average of NOx over the flat and elevated terrain.

with high concentrations in a huge region, especially in the mountainous and hilly terrain. SO_2 and NO_2 pollution are worse than TSP since their concentration exceeds the limitation threshold by 8.1 and 14.2 times. The 99th percentile region simulation also indicates the high possibility of air pollution. The NO_2 content under long-term conditions is projected higher than the acceptable amount. Cross-contamination and the cumulative effect of multiple emission sources, in reality, will make air pollution in Cam Pha City more severe.

Author contributions

Quan Anh Tran and Ngoc Hong Thi Nguyen proposed the topic, conceived and carried out the simulations; Phi Quoc Nguyen, Anh Mai Nguyen and Quan Anh Tran contributed to the study's design, analyses and interpretation of the results; Quan Anh Tran drafted the first manuscript and all other members contributed to the final manuscript; All authors read and approved the final manuscript.

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