

Assessment of the Air Environment in Open-Pit Coal Mining Area in Cam Pha Region, Quang Ninh Province

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Abstract: *Quang Ninh is the main coal mining province in Vietnam, with open-pit coal mining activities concentrated in the Cam Pha area. Coal mining activities, on the one hand, bring about economic development for the locality, but on the other hand, also cause impacts on the landscape, ecology, and environment, generating dust, noise, emissions, and potential risks of environmental incidents. By collecting and synthesizing documents, conducting field surveys, consulting with the community, and analyzing statistics, the research has summarized the air environment issues in the open-pit coal mining area of Cam Pha, identifying sources of impact on air quality. The main source of dust and gas is concentrated in the coal mining site area because, to carry out coal mining activities in open-pit mines, it is necessary to remove the soil and rock covering the surface using large machinery, such as excavators and blasting drills. Additionally, dust and gas emissions are generated by vehicles transporting waste soil and rock from the mining area to the dumping areas. The air environment in the open-pit coal mining area in Cam Pha is affected by total suspended particulate matter, exhaust gas, and explosive gas, especially in the dry season. In particular, the monitoring results of high dust concentrations are concentrated in the opening coal area, the transportation route, and the screening area. The study also synthesizes the technological measures currently being used in dust control and reducing emissions into the environment at current open-pit coal mining units. From there, the researchers proposed mining management solutions, implementing measures to minimize dust emissions to protect air quality in the Cam Pha area, ensuring sustainable economic development for the coal industry and Quang Ninh province.*

Keywords: *air quality, open-pit coal mining, Cam Pha area*

1. Introduction

Coal mining activities play an important role in the economic development of the country. Among them, the open-pit coal mining plays a key role in the productivity of the Vietnamese coal industry. According to statistics, the volume of coal from open-pit mining is from 55 to 65% of total coal production. At present, in the Cam Pha area, there are three open-pit mines having an annual exploitation capacity exceeding 2 million tons/ year, including Cao Son, Coc Sau, and Deo Nai mines. Besides the economic development values for the locality, it also causes negative impacts on the landscape and ecology due to dust, noise, emissions, and potential risks of environmental incidents. Research on the assessment impact of open-pit coal mining on the environment is necessary and has been carried out in some research projects in the world where coal mining is taking place, such as:

In the study of A. K. Sharma and K.A. Siddiqui, the air quality around the Jayant open-pit coal mining, in Sidhi district of Madhya Pradesh, India, was assessed for a period of 2 years from January 2007 to December 2008 with the following parameters: total suspended particles (TSP), settled dust, sulfur dioxide (SO₂) and nitrogen oxides (NO) at 05 monitoring stations located in residential areas, mining areas and office areas. The results showed that parameters SO₂ and NO tended to increase in winter and decrease in the rainy season, while TSP and settled dust parameters peaked in summer. The SO₂ and NO concentrations at the Jayant coal mine area were below the permissible limits of the Indian NAAQS and CPCB standards, but the TSP and settled dust concentrations were much higher than these limits. The research results also showed that the TSP and deposited dust samples contained heavy metals, of which zinc and manganese had the highest concentrations, followed by Pb, Cd, Ni, and Cr. In this article, the author suggested solutions for controlling settled dust and TSP, especially to minimize the release of Zn and Mn into the air environment. (Sharma et al, 2010).

In the study of J. I. Huertas in 8 open-pit coal mines in Northern Colombia (Huertas et al, 2012) in 2009, the coal production was estimated at about 70 million tons/year. The air quality results surrounding

mining from the Colombian monitoring network built since 2007, the total suspended particulate (TSP) and PM10 are higher than the permissible limits. The study conducted an emission inventory for these two parameters and established a dust dispersion model using the ISC3 and AERMOD simulation models based on the data series of 2008 and 2009, and then compared them with actual measurements from the air quality monitoring network. Based on the modeling results, the mining area was classified into zones of varying dust pollution with high, medium, and low levels, according to Colombian air quality standards. The article also proposed solutions to deal with air pollution in these areas.

In the study of Mishra, N., Das, N., the authors assessed the impacts of mining activities in Talcher Coalfield in India on air, water, and noise pollution. The study showed that the concentration of suspended dust was high at sampling locations. In addition, the increasing air pollution is caused by uncovered coal transportation and a lack of water sprinkler systems. The study also conducted a survey and community consultation in 600 households in 6 villages. The assessment results showed that out of 450 households near the mining site, about 96.44% of the people believed that the mining management of the Mahanadi Coalfields Limited company had not implemented any mitigation measures. Therefore, the study proposed comprehensive management solutions to minimize air pollution at Talcher Coalfield, ensuring the livelihood of local people. (Mishra et al, 2020)

In the study by Ang Li, air pollution monitoring was conducted at the Qipanjing coal mine in Inner Mongolia, China. In this study, the status and factors promoting air pollution generation in the area were assessed. The FTIR spectroscopy was used to measure inorganic compounds in dust with a size smaller than 2.5 μm . The research evaluated the spatial and temporal distribution characteristics of pollutants, including PM2.5, PM10, SO₂, NO₂, O₃, and CO. The study also calculated a composite AQI index to assess the air quality in this area. The study proposed solutions to protect the air environment in the study areas. (Ang Li et al, 2021)

The main sources of air pollution in Petroșani, a traditional mining area in Romania, were assessed by Rezmerița. Initial findings point to a deterioration of local air quality indicators related to decarbonization, based on the changes in measured values in one of the bituminous coal mines. The monitoring of the air quality parameters was conducted at six points on the road that crosses the city in 2020. The research results show that the main air pollution in Petroșani mining is related to the transit road. And the dispersion of pollutants is influenced by the weather. The total particulate matter in some places exceeds the standard in the average humidity and temperatures (between 30 ÷ 40% and 19 ÷ 23°C), while both NO₂ and total particulate matter exceed with medium humidity (36 ÷ 43%) and high temperatures (28 ÷ 31°C). The solutions to protect the air environment in the study areas were given out. First of all, it is more important to renounce the use of stoves for home heating, use clean energy, and limit the use of fossil fuels. Next, compliance with environmental requirements is necessary to protect the air environment in this study area. (Rezmerița et al, 2022)

Mishra assessed the impact of coal mining and utilization on the air environment and vegetation in Dhanbad district, Jharkhand, India. The AQI index is used to evaluate the air quality, and the APTI index is used to assess the perennial tree species. The study results show that the highest AQI values are in the Jharia area, and the lowest are in the Baramuri area. And PM10 and PM2.5 contributed the most to the AQI values. When analyzing the particles, heavy metals such as Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were found. The study calculates the APTI of the tree species to assess the effects of air pollution on the physiological and biochemical properties of plants. Therefore, *F. Benghalensis* is the most effective tree for absorbing and regulating air pollution in this area. (Mishra et al, 2024)

From that, the air quality in open-pit coal mining areas has attracted the interest of researchers around the world. Most studies have clarified that TSP and PM10 dust are the main sources of dust generated from open-pit mining activities. In addition, PM2.5 dust also contributes greatly to the calculation of the AQI index. The research is based on environmental monitoring results from automatic monitoring stations, sample analysis in the laboratories, and the use of the AQI index to assess the overall air quality of the study area. The results of studies in the world are a good basis for comparison with studies on the air environment conducted in coal mines in Vietnam, and for the direction of the research of this article. According to the results of the synthesis, the assessment of the impact of mineral exploitation activities on the environment has been carried out in recent years. But the studies assessing the effect of open-pit mining on the air environment are fewer. According to studies, the generation of waste rock from mining activities is an indirect cause of dust emissions, reducing the quality of the air environment in residential areas around mining. Coal mines often contain high levels of Sc, Ti, Mn,... elements. In addition, sulfide minerals in coal

also contain Zn, Cd, Hg..., which makes them toxic to human health. Some research has assessed the source, status of the pollution environment, and management and mitigation solutions, specifically in the following study by Nguyen. According to research, the air environment in some coal mining areas has dust, toxic gas, explosive gas, and noise levels exceeding the permitted standards for ambient air quality, especially in Cam Pha, Uong Bi, Mao Khe, Ha Khanh, Ha Lam, Ha Trung, Ha Tu, and Ha Phong wards - Ha Long City. In particular, the dust in processing coal mining areas exceeds the permitted standards by 1.2 ÷ 5.2 times, and exceeds standards by about 3.3 times in neighboring residential areas. In recent years, coal mining companies have invested in modern technology and solutions to protect the environment, so the air quality has improved. (Nguyen, 2016)

The results of domestic studies have not yet assessed in detail the main sources of dust and gas emissions, as well as the amount and type of dust in open-pit coal mines in the Cam Pha area. At the same time, they have not yet listed the solutions and technologies being used to control the air environment in the mine area. Therefore, it is still necessary to conduct studies to specifically analyze and evaluate the impact of coal mining activities on air quality in the Cam Pha area. After that, a long-term plan is developed to control and respond to environmental risks, minimize impacts, and effectively manage coal mining activities to serve the sustainable socio-economic development of the locality.

2. Data and methods

The paper used data from the report on coal mining operation results, the 2024 environmental monitoring report of three open-pit coal mining companies (*Deo Nai Coal Joint Stock Company, Coc Sau Coal Joint Stock Company, and Cao Son Coal Joint Stock Company*). The main methods used in this article are as follows:

** Method of collecting and editing documents:*

Data on the results of coal mining operations and periodic environmental monitoring in 2024 in the Cam Pha coal mine area were collected from Deo Nai, Coc Sau, and Cao Son Coal Joint Stock companies. In which the air quality monitoring data is collected in 2 seasons: rainy season (from April to the end of October), and dry season (from November to March) from the Information, Technology, and Environment Joint Stock Company – Vinacomin. In addition, the authors also collected automatic monitoring data from January to December 2024 at the monitoring station of the Department of Natural Resources and Environment of Quang Ninh province (now the Department of Agriculture and Environment of Quang Ninh province). These data will be used to assess the causes of dust emissions in the mine area and the impact of coal mining activities on the surrounding environment, especially the air environment. In addition, the authors also collected data on climate, rainfall, and temperature in the research area as a basis for assessing the potential for dust emissions into the environment.

** Field survey method and community consultation:*

The research team performed an on-site survey in the Cam Pha open-pit mining area, assessed works and equipment to reduce air pollution, and directly consulted with environmental officers on environmental management at the mines. The study also conducted several rapid tests on air quality and collected dust samples at the mining site, transportation routes, and waste disposal areas. The monitoring parameters are total suspended, PM10, SO₂, NO₂, CO, H₂S, CH₄, and vibration, noise. To perform rapid field measurements of dust, the research team used the CEL-712 MICRODUST PRO electronic dust concentration meter (Total dust measurement) from Casella - UK. The device has a wide measuring range from 0 to 250 g/m³ (automatically selects the measuring range), resolution: 0.001 mg/m³; Zero stability: < 2 µg/m³. The total monitoring locations are 39 sites (17 sites are in Coc Sau mining, 17 sites in Cao Son, and 5 sites in Deo Nai), and are shown in Fig. 1. Data on dust and gas emissions, noise, and vibration concentrations after measurement and analysis are compared with corresponding standards such as: QCVN 05:2023/BTNMT (National technical regulation on ambient air quality – average 1h); QCVN 26:2010/BTNMT (National technical regulation on noise); QCVN 27:2010/BTNMT (National technical regulation on vibration, 6h ÷ 21h); QCVN 24:2016/BYT (Noise at work); QCVN 27:2016/TT-BYT (Vibration at work).

** Expert method:*

The consultations were conducted with experts in the field of environment and mining to share experiences and propose solutions suitable for Vietnam to minimize the impact of coal mining on air quality in the Cam Pha area, Quang Ninh province.

Tab. 1. Climate characteristics of the Cam Pha area in 2024 (National Statistics Office, 2024)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Temperature, °C	17.9	18.8	20.7	26.6	27.6	29.2	28.8	29.2	28.1	26.3	23.8	18.5
Humidity, %	82	85	86	87	85	87	88	86	85	72	72	69
Rainfall, mm	56.6	9.6	23.2	104.6	354.7	723.0	949.4	341.9	697.5	7.6	1.8	0.9

3.2. The status of open-pit coal mine activities in the Cam Pha area

Most of the coal open-pit mining in the Cam Pha area is exploited using a trench system to open the seam along the coal seam wall. Only the left area of Coc Sau mining is exploiting the seam by trenching in the coal, while the East Thang Loi of Coc Sau mining and Lo Tri of Deo Nai mining are exploiting from the pillar to the seam wall. In recent years, due to deep mining, which is below the level of natural drainage, the mine has increased speed, applied hydraulic backhoes to combine digging trenches to open the seam, and drained the mine bottom. Details on the exploitation status of open-pit coal mining in the Cam Pha area are shown in Tab. 2.

Tab. 2. The information on the status of open-pit coal mining in the Cam Pha area (Information, Technology, and Environment Joint Stock Company – Vinacomin, 2023; Cao Son coal mine joint stock company - TKV, 2024)

Target	Unit	Coal open-pit mining		
		Deo Nai	Coc Sau	Cao Son
Acreage of the exploitation area	Km ²	5.8	4.0	6.07
Mining capacity	million tons of raw coal/year	1.62	1.5 ÷ 1.75	1.2 ÷ 4.5
Amount of soil removed	million m ³ /year	22	19 ÷ 28	15 ÷ 56
Mining pit bottom elevation	m	-250	-300	-230

Nowadays, the exploitation of coal in open-pit mining uses vertical layer extraction technology. The waste disposal technology of mines in the Cam Pha area uses combined external and internal waste dumps. In particular, the waste soil and rock have been transported by cars combined with scrapers and conveyors. All vehicles are covered to limit the dispersion of dust into the environment.

3.3. The status of air quality in open-pit coal mining areas in the Cam Pha area

At open-pit coal mines, drilling and blasting are used to exploit coal and remove the soil and rock covering the surface, and excavating with large machinery such as excavators, loaders, etc. Blasting is an essential component of open-cut mining. Using large amounts of explosives in the blasting process at open-pit mines, which makes dust disperse up to 100 to 150 m high. The concentrations of dust after the explosion can reach from 540 to 4,500 µg/Nm³ at a distance of 30 ÷ 40 m. In addition, dust and emissions are also generated from vehicles on the route that transport waste soil and rock from the mining area to the disposal sites. The research results also show that the air environment in the Cam Pha open-pit coal mining area is mainly affected by TSP dust, emissions, explosive gases, and noise in the dry season. In particular, the monitoring results of high dust concentrations were concentrated in open-pit coal mining areas, transportation routes, and screening areas.

Based on the results of global research, dust generated from open-pit mining activities is often of a relatively large size, and the monitoring results mainly assess the TSP dust. The PM_{2.5} dust content is relatively low and is mainly used in calculating the AQI index. The results of collecting PM₁₀ dust monitoring data at coal mines show that the concentration is much lower than QCVN 05:2023/BTNMT. The monitoring results vary between locations and times, and details are in Tab. 3. Therefore, this paper focuses on assessing the impacts of open-pit coal mining activities in the Cam Pha area on the regional air environment by the TSP dust.

The results of 4 sessions of air quality monitoring at 17 locations of the Coc Sau coal mine show that in the rainy season, the average TSP dust concentration ranges from 130 µg/Nm³ (in the guest house area) to 279.5 µg/Nm³ (in the screening area 19/5 and coal construction site 2). However, the TSP dust concentration increases in the dry season, averaging from 135.5 µg/Nm³ (in the guest house area) to 280 µg/Nm³ (in the screening 1 - screening belt construction site). The average SO₂ concentration in the rainy season is from 62.5 µg/Nm³ (in the guest house and residential area) to 73.5 µg/Nm³ (in the sewage area No. 1,2 - screen 1) and the average SO₂ concentration in the dry season is changes from 61.5 µg/Nm³ (in

the residential area of Cam Phu ward) to $74 \mu\text{g}/\text{Nm}^3$ (in the sewage area No. 1,2,3 - screen 2). (Information, Technology, and Environment Joint Stock Company - Vinacomin, 2024). The changes in TSP dust concentration at monitoring locations in the rainy and dry seasons are shown in Figs 2 and 3.

Tab. 3. The monitoring results of PM10 dust concentration at Cao Son coal mine in 2024 (Information, Technology, and Environment Joint Stock Company – Vinacomin, 2024)

Sample	Location monitoring	PM10 dust concentration, $\mu\text{g}/\text{Nm}^3$			
		Session 1	Session 2	Session 3	Session 4
CSnK6	In the screening area 2	51	58	56	64
CSnK9	Stone conveyor crushing station	48	52	60	69
CSnK11	Bang Nau waste rock dump +170	52	66	58	61
CSnK16	Foot of Bang Nau waste rock dump, location 2	60	65	60	63
CSnK24	Coal and soil transportation route in the mine	40	51	49	52
CSnK26	East of the Cao Son mining, level +200	59	64	57	62
CSnK27	In the central mining area, level -40	55	59	60	64
CSnK29	Transportation routes to the Bang Nau waste rock dump	54	59	63	69
QCVN 05:2023/BTNMT (average 1h)		100			

At Cao Son coal mine, the results of 4 monitoring sessions of air quality in the rainy season at 17 locations had an average dust value ranging from $248.5 \mu\text{g}/\text{Nm}^3$ (in the transportation route) to $293 \mu\text{g}/\text{Nm}^3$ (in the central mining area), increased in the dry season, the measured value changes from $259.5 \mu\text{g}/\text{Nm}^3$ (in the residential area of Duong Huy commune) to $297.5 \mu\text{g}/\text{Nm}^3$ (in the screening area 2). Thus, dust concentration is higher in the dry season at locations with large amounts of dust, such as the screening area and residential areas, which are impacted by coal mining activities, daily activities, and transportation. Similarly, in the rainy season, SO_2 concentration varies from $48.5 \mu\text{g}/\text{Nm}^3$ (in the office area) to $71 \mu\text{g}/\text{Nm}^3$ (in the screening areas 1, 2, 3). In the dry season, SO_2 concentration increases in areas with many mining activities, varying from $44.5 \mu\text{g}/\text{Nm}^3$ (in the Dong Cao Son mining area level +80) to $74 \mu\text{g}/\text{Nm}^3$ (in the screening area 2). (Information, Technology, and Environment Joint Stock Company - Vinacomin, 2024).

The results of 4 monitoring sessions of air quality at 5 locations of Deo Nai coal mine showed that the average dust concentration value in the rainy season ranged from $215 \mu\text{g}/\text{Nm}^3$ (in the mechanical workshop area) to $279 \mu\text{g}/\text{Nm}^3$ (in the coal warehouse and screen 5 area) and increased in the dry season, ranging from $226 \mu\text{g}/\text{Nm}^3$ to $293 \mu\text{g}/\text{Nm}^3$. SO_2 concentration in the rainy season varied from $35.5 \mu\text{g}/\text{Nm}^3$ (in the mechanical workshop area) to $66 \mu\text{g}/\text{Nm}^3$ (in the coal warehouse and screen 5 area) and increased from $41.5 \mu\text{g}/\text{Nm}^3$ to $89.5 \mu\text{g}/\text{Nm}^3$ in the dry season. (Information, Technology, and Environment Joint Stock Company - Vinacomin, 2024).

Based on the research results, the rainfall affects the dispersion of dust gas in open-pit coal mines, helping to dilute and reduce dust concentrations. And to assess the relationship between the concentration of TSP dust and rainfall, the research team used the dust concentration data in 2024 of Deo Nai coal mine from the automatic monitoring station of the Department of Natural Resources and Environment of Quang Ninh province, and the average monthly rainfall at the monitoring station of Quang Ninh province. The correlation graph of the TSP dust concentrations and rainfall was built, and is shown in Fig. 4. According to the graph, the dust concentration tends to decrease during the rainy months, and is lowest in June and July, and highest in November and December. In particular, when the rainfall in July reached 949.4 mm, the TSP dust concentration measured at the mining area was $250 \mu\text{g}/\text{Nm}^3$, and it is much lower than in December when the rainfall is zero.



Fig. 2. The monitoring results of SO₂ and TSP dust in the rainy season of 2024 at Coc Sau Coal Joint Stock Company - VINACOMIN (Information, Technology, and Environment Joint Stock Company – Vinacomin, 2024)

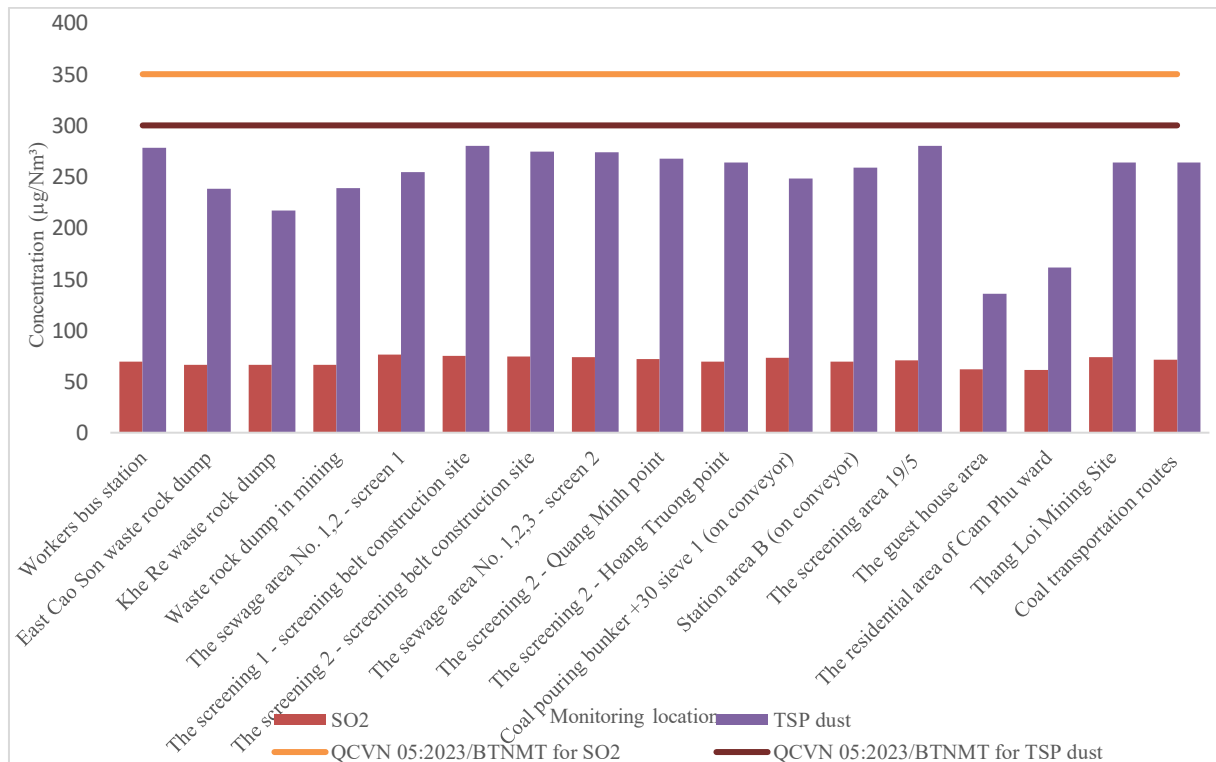


Fig. 3. The monitoring results of SO₂ and TSP dust in the dry season of 2024 at Coc Sau Coal Joint Stock Company - VINACOMIN (Information, Technology, and Environment Joint Stock Company – Vinacomin, 2024)

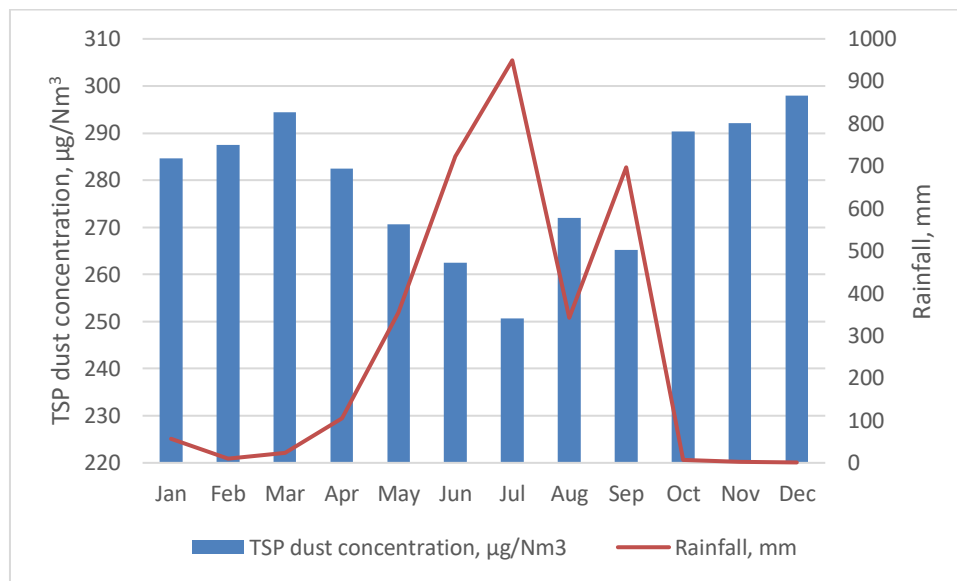


Fig. 4. Graph showing the relationship between the TSP dust concentration and rainfall

The TSP and SO₂ values at all measurement points in both the rainy and dry seasons at 3 open-pit coal mines meet the permissible standards (below the level of 300 µg TSP/Nm³ and 350 µg SO₂/Nm³ according to QCVN 05:2023/BTNMT). This result is lower than the result of Nguyen’s research, which shows that the dust content in central mining and processing areas exceeds the permissible standards by 1.2 ÷ 5.2 times and exceeds standards by about 3.3 times in the neighboring residential areas (Nguyen, 2016). This shows that coal mines in the Cam Pha area have been effectively applying solutions and measures to minimize dust and emissions. In addition, the monitoring results show that the air concentration increases from 1 to 5% over time and location. Total suspended dust and settled dust are the main sources of emissions from open-pit mining activities. The concentration of TSP and SO₂ increases in the dry season. The reason is that rain dilutes and cleans the air, so the concentration of dust at all locations tends to decrease. This conclusion is also consistent with the research by Ashish, who assessed and managed the air quality of Jayant open-pit coal mining (Ashish et al, 2010), and the research results by Rezmerița in Romania (Rezmerița et al, 2022).

Besides, the TSP and SO₂ concentrations change between monitoring locations. However, the fluctuation of TSP dust concentration between locations is higher than the SO₂ concentration, distributed in mining pits, coal screening areas, waste soil and rock dumps, transportation routes, and worker bus stations. This result indicated that the main source of air pollution is dust from drilling, blasting, open-pit mining, leveling, dumping, coal screening, and transportation of waste rock and coal. This conclusion is also completely consistent with the research results presented by authors Nguyen (Nguyen, 2016), Mishra (Mishra et al, 2020), and Rezmerița (Rezmerița et al, 2022).

In summary, the research results have assessed the current status of air quality in the open-pit coal mine of the Cam Pha area, clarifying the main sources of dust emissions. Among that, the TSP dust is the type of dust with the largest amount generated and is highly concentrated in the dry season. From there, controlling sources of air pollution will help improve the environmental quality of the research area.

3.4. The status of air environment protection solutions in open-pit coal mining in the Cam Pha area

The open-pit coal mines in the Cam Pha area have been applying solutions and measures to reduce dust and emissions, such as installing fixed dust suppression misting systems and high-capacity dust suppression misting machines in areas where large dust particles are generated. That position includes screening clusters, gas chutes, crushing stations, and waste dumps. In addition, dust suppression misting guns and specialized watering trucks with a capacity of 12 ÷ 50 m³ are also used on the transportation route; building dust-blocking walls; installing conveyor belts to transport coal from the industrial yard to consumption (Information, Technology, and Environment Joint Stock Company – Vinacomin - Vinacomin, 2023; Cao Son coal mine joint stock company - TKV, 2024).

According to the results of the documents collection, investigation, and field survey at coal mines, most of the open-pit coal mines in the Cam Pha area use misting systems to control dust in the screening area, crushing station, and coal storage with a spray radius of 70 m. In addition, the misting guns with a

spray radius of 110 ÷ 150 m are used to minimize dust in the waste soil and rock dump areas. The mines also built the retaining wall systems with 7 ÷ 17 m height to limit dust spreading far away during the production and processing of coal. The companies in the Cam Pha area also use large-tonnage vehicles to reduce traffic volume and water vehicles to prevent dust dispersion during the 3 shifts. Carrying out spraying on transportation routes, technological areas (both mining areas and residential areas), and warehouse areas where mechanical equipment is working. At the operating drilling machines, all mines use dust suppression methods by mixing compressed air and water, and the hydraulic drilling machines with dust filters to limit dust dispersion into the environment.

Currently, the Coc Sau coal mine uses 4 fixed high-pressure dust suppression misting systems in the coal screening and storage areas, 2 misting gun systems in the waste rock dump area, and 1 dust suppression system along the transportation route. Coc Sau coal mining also uses 06 Hyundai trucks with a capacity of 16.5 ÷ 20 m³/truck and 04 Komatsu HD325 trucks with a capacity of 35 m³/truck to carry out watering work, minimizing dust generation in the environment.

Deo Nai coal mine uses 2 high-pressure misting systems to suppress dust, and the retaining wall systems combined with misting in coal storage areas, screening clusters on the +80 and +260N level. Besides that, using 4 system misting guns with a capacity of 30 m³/h, located in waste areas, mining areas, and on the transportation route. The mine uses 2 dust-proof mesh systems combined with misting to suppress dust in coal storage areas at the +80 level and +260N level. At Deo Nai company, there is still a specialized transport workshop to carry out watering and dust suppression with over 100 staff and 08 water trucks with a capacity of 13 ÷ 50.5 m³/truck.

At Cao Son coal mine, 12 misting systems are used to suppress dust, with 152 spray columns that have a capacity of 50 m³/h, 05 misting guns, and 19 watering vehicles to clean the road. Details of the vehicles are shown in Tab. 2.

Tab. 2. Summary of water spray vehicles for watering the roads of Cao Son coal mine (Cao Son coal mine joint stock company - TKV, 2024)

Vehicle type	Numbers	Tank volume (m ³)
High-pressure watering truck	03	
Huyn dai HD320	02	17.2
Caterpillar 773E-GF13W	01	50
The washing road vehicle	16	
Kamaz Stec	04	12
Caterpillar	05	35
Komatsu HD465-7R	02	50
Komatsu HD325	03	35
Hyundai HD310	02	17

In general, at open-pit coal mining in the Cam Pha area, the solutions have been applied to controlling air pollution. Spraying water to suppress dust, planting trees, and simple dust filtering equipment have been used. The advantages of the solutions are high feasibility and low investment costs. In environmental management, coal mining companies in the Cam Pha area implemented environmental protection works and measures during the project operation and have been granted a Certificate by the General Department of Environment - Ministry of Natural Resources and Environment. In addition, the companies have been granted a Certificate of Environmental Management System by ISO 14001:2015 for the field of coal mining, processing, and trading according to the requirements of the Law on Environmental Protection and Decree No. 40/2019/ND-CP of the Government. The mines have developed an air environment monitoring program with objectives, parameters, monitoring points, frequency, monitoring time, and other monitoring parameters. Comply with periodic monitoring reports to control environmental quality. However, air pollution control is still not thorough due to the large exploitation area and a lack of human resources for technology management and monitoring. Therefore, improving the effectiveness of environmental protection for the study area needs attention.

3.5. Proposing solutions for managing the air environment in open-pit mining in Cam Pha areas

First of all, to improve the efficiency of air environment management in the Cam Pha open-pit coal mining area, it is necessary to apply advanced technical and technological solutions, such as:

- Continue to strengthen environmental management and monitoring in the mines. Need to conduct additional monitoring of PM_{2.5} dust. This data is a good basis to assess the impacts of PM_{2.5} on health, and to calculate the AQI index for the air environment.

- Continue to use misting technology to suppress dust at high dust generation points, invest in additional high-capacity suppression misting machines to control dust at times and locations with high risk of dust generation, especially in the drilling and blasting areas, and route transportation.

- Comply with regulations on means of transport, cover coal transport vehicles with tarpaulins or closed containers. The transportation needs to be washed before leaving the mine area.

- Use clean fuel for vehicles and mining machinery (CNG, LNG, electricity).

- Continue to carry out synchronous implementation of environmental management and mine safety, periodically report to environmental management agencies, implement environmental protection deposits, make annual investments in mine environment improvement, upgrading, and restoration... Build an ISO 14001 environmental management system.

- Continue to cover waste rock and soil dumps and transportation routes with native trees, especially plants that have good dust absorption capacity and minimize dust and noise dispersion. Besides, planting trees creates a landscape in the mines.

- Building a team of specialized environmental management staff with high professional qualifications.

- Regularly inspecting and checking compliance with environmental protection regulations at coal mining enterprises.

In addition, to ensure the treatment and minimization of dust generated, based on the extent of exploitation and investment costs of coal mines, it is necessary to continue implementing the technical and technological solutions in the next phase, including:

- Build additional separate coal transport routes or coal conveyor belts with dust-reducing covering systems to avoid affecting the surrounding area.

- Build an effective dust collection and treatment system, using advanced dust filtering equipment, such as a cyclone or bag filter.

With long-term plans, coal mines in combination with the management agencies of Quang Ninh province continue to implement specific solutions as follows:

- Prepare reports and public information on air quality for the community through the media.

- Building an automatic air quality monitoring system in key areas, connecting with the control center to monitor and promptly handle incidents.

- Developing environmental data management software, integrating information from different sources to help monitor, analyze, and evaluate the air quality exactly and effectively.

- Propose to state management agencies to add more preferential policies for mining enterprises that apply cleaner production, invest in green and friendly environmental technologies, and implement well in environmental management, towards sustainable development.

4. Conclusion

The air quality in the Deo Nai, Coc Sau, and Cao Son open-pit coal mines remains within standards, as indicated by the TSP dust and SO₂ levels at all monitoring points, which are below the limits set by QCVN 05:2023/BTNMT. The average TSP dust concentration ranges from 130 µg/Nm³ to 297.5 µg/Nm³. Pollutant levels in these three mines tend to drop during the rainy season and rise in the dry season. However, the variations are not significant. SO₂ concentration in the rainy season varied from 35.5 µg/Nm³ to 73.5 µg/Nm³ and increased from 41.5 µg/Nm³ to 89.5 µg/Nm³ in the dry season.

The main sources of dust and emissions in coal mining areas are from blasting, rock excavation, and screening activities. In addition, vehicles and machinery also contribute to the release of substances that impact the air environment, and the level of impact varies depending on the area.

Solutions to reduce dust from blasting, coal transportation, and dumping areas, as well as improving emissions from vehicles, are fundamental steps toward cleaner air in the open-pit mining region of Cam

Pha. The coordinated implementation of solutions that combine monitoring and environmental surveillance systems will ensure effective control of air pollution. Need to carry out monitoring of PM_{2.5} dust to assess its impacts on human health and the environment. Finally, the mines must continue to adhere to legal regulations regarding waste management to maintain environmental quality and promote green, sustainable development.

In summary, the research results of this paper have assessed the current status of air quality in the open-pit coal mining area of Cam Pha, Quang Ninh province, as well as the current management status being implemented in coal mines. However, the paper has not yet analyzed the contribution rate of emission sources to the air quality in the area, and estimated the effectiveness and cost of the proposed solutions to assess the feasibility of implementation. Therefore, it is necessary to continue conducting studies to ensure effective management of air quality in the coal mine area, towards sustainable development.

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