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Development of Emission Factors for Quantification of Blasting Dust at Surface Coal Mines

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ABSTRACT

Environmental impact assessment (EIA) and environmental management plan (EMP) is a statutory requirement for execution of new mining projects or for expansion of the operating projects. For this purpose, quantification of blasting dust emission is required. This can be done by developing emission factors for blasting. The concept is similar to that of specific charge in blasting. For mining operations other than blasting, quantification of dust can be done using emission factors. Emission estimation techniques are very limited for blasting. In this study, the emission factors were developed by carrying out a detailed field study at one of the largest opencast coal mines of India in all four seasons. Data on atmospheric and meteorological conditions were generated by installing sodar and automatic weather station at the mine site. Respirable dust samplers were installed for monitoring of the dust emitted during coal or overburden bench blasting. Emission factors for dust concentrations were developed in gram per cubic meter of rock excavated. The developed emission factors were used to estimate dust emissions for adjacent mines due to similarity in mining and meteorological conditions. Seasonal variations in moisture contents in benches, where dust was monitored, indicated the lowest emission factors in monsoon due to high moisture in the bench materials. Similar field studies were also conducted at another coalfield of India for two seasons. It was found that the emission factors are site-specific.

Keywords: *Emission Factor, Blasting Dust, Particulate Matter, Surface Coal Mines*

1. Introduction

Emission factor is a representative value to estimate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. It is important for developing emission control strategies by Central and State Government, consultants, and industry [1]. Among different fugitive dust sources of mining activities like topsoil stripping, drilling, overburden and coal removal, material hauling, stock piles, etc. [2,3]; blasting produces very large quantities of dust. The dust produced due to blasting in the form of total suspended particulate matter (TSP) and particulate matter less than 10 μm (PM_{10}) affects the surrounding environment, human beings, animals, and plants depending on the meteorological conditions at the mine site.

The concept of emission factor is analogous to specific charge in rock blasting. Specific charge is a measure of the mass of an explosive required to break a unit volume or a unit mass of the rock. Considering the explosive mass in units of kilograms and the rock quantity in cubic meters or tons, the specific charge can be expressed in kg/m^3 or kg/t [4]. Specific charge indicates how much explosive is needed for fragmentation of one cubic meter of rock whereas emission factor indicates the amount of dust emitted into the atmosphere during blasting of one cubic meter of rock. A lower emission factor is desirable as a higher value can cause air pollution in the mine and surrounding areas.

Emission factor can be used to quantify the dust generated by blasting at the planning or operating stage of a mine. Hence this is a useful tool for preparation of environmental management plan. Previous work on air pollution due to surface coal mining mostly deals with monitoring and analysis of dust generated by different mining operations. According to the United States of Environmental Protection Agency [5], blasting presents formidable logistic difficulties in sampling or sampler deployment. Hence USEPA did not recommend for further field study.

Data from source-specific emission tests are usually preferred. Realistic emission factors can only be developed with actual emissions data. The first issue which must be faced while developing an emission factor is to define a source category. In some cases, this may be fairly simple and straightforward. But in case of fugitive particulate matter emission, the definition of a source category generally involves some compromises [2]. Different mining activities have been categorized into different source categories such as drilling as point source, coal loading as point or area source, dragline as point or area source, dozer as line or point source, blasting as area source, etc [6]. For blasting, most of the researchers have developed single-valued or predictive equations for calculating emission factor in kilogram per blast and some have estimated in kilogram per tonne of explosive consumed. Often in the mine, the size of blast varies from blast to blast. Therefore, the emission factors can be developed in gram per cubic meter of rock excavated. An attempt was made to develop emission factor for PM_{10} and TSP by carrying out a detailed study at large opencast coal mines in India. Application of the emission factor in other mines is also presented.

2. Overview on Blasting Emission Factors

The emission factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant depending on the operations carried out at surface mines [1]. For example, it is expressed in kilogram per vehicle kilometers traveled (kg/VKT) for scrapers, kg/hr for bulldozer, kg/t for truck dumping coal or overburden, etc. Similarly emission factors for blasting have been expressed in different units by the different countries.

Different researchers have developed different emission factors for blasting under different mining and meteorological conditions. Most of the works related to fugitive emissions have been undertaken in the United States. Some work has also been undertaken in Australia, although the Australian work is not as comprehensive as that of the US [7]. It is worth pointing out that the USEPA emission factors are published and are widely referred. The most comprehensive compilation of emission factors is the USEPA document referred as AP-42 [8]. The emission factors developed and used by various countries are summarized below.

2.1. Emission Factors for USA Mines

Cole and Kerch [3] reported TSP emission factor as 14.3 to 85.3 lb/blast for overburden and 25.1 to 78.1 lb/blast for coal [9]. Emission factor for PM_{10} is not given. Axetell and Cowherd [10] developed emission factor equation for coal or overburden for 30 μm size particles as $0.00022(A)^{1.5}$ in kg/blast, where A is the horizontal area with blasting depth 21 m as it is reported in USEPA [1].

Axetell and Cowherd [11] developed the emission factor equation for TSP as 961 $A^{0.8}$ $D^{-1.8}$ $M^{-1.9}$ lb/blast for coal or overburden, where A is the area blasted (sq ft); D is the blasthole depth (ft); and M is the moisture content (%). For the estimation of particulate < 15 μm, the equation is given as 2550 $(A)^{0.6}/(D)^{1.5}(M)^{2.3}$ and for calculation of particulate < 2.5, the values obtained by TSP equation should be multiplied by 0.030. Single valued emission factors have also been mentioned for different mines. For mine type A, the single-valued TSP emission factor for overburden blasting is mentioned as 1690 lb/blast, but for coal this value is not given. For mine type C, TSP emission factor for coal and overburden is 25.1 lb/blast and 14.2 lb/blast respectively. For mine type D, TSP emission factor for coal is 78.1 lb/blast. For overburden, the value is not given. For mine type E, the TSP emission factor for coal and overburden is 72.4 lb/blast and 85.3 lb/blast respectively. This has been reported under section 5.5 and 8.5 of "Fugitive Dust Emission factor Update for AP-42" [6].

The current version of AP-42 section 11.9 was first drafted in 1983 using the field data collected during the late 1970s and early 1980s at Western surface coal mines. Minor changes related to emissions from blasting and estimating PM_{10} emissions were made in this version [6]. According to current version, the general equation for TSP and PM-15 is reported as $e = k\ (A)^a/(D)^b\ (M)^d$, where e is the emission factor expressed in mass of emissions per blast; A is the area blasted (area); D is the hole depth; M is the material moisture content (%); and k, a, b, and c are the regression values. The USEPA has reported emission factor for particulate ≤ 30 μm for coal or overburden as $0.0005A^{1.5}$, where A is the horizontal area with blasting depth ≤ 70 feet. For PM_{10}, the values obtained from this equation will be multiplied by 0.5.

2.2. Emission Factors for Australian Mines

National Pollutant Inventory [12] reported emission factors for Australian mines based on the particles emitted per tonne of explosive used. The emission factor is reported for the different particle size ranges emitted per tonne of the explosive used. The emission factor for particle size 0-2.5 μm, 2.5-15 μm and 15-30 μm is 5.1 kg/tonne, 46.0 kg/tonne and 49.9 kg/tonne respectively. The emission factor for overburden blasting is 0.00022 $A^{1.5}$ kg per blast, where A is the area to be blasted in m^2.

Environment Australia [13] formulated the guidance for application of emission factors in Australian conditions. In this report, equation for TSP estimation is mentioned as $0.008A^{1.5}$ kg/blast; where A is the area blasted in m^2. For PM_{10} estimation, the value obtained by TSP equation should be multiplied by a factor 0.52. Later on, Environment Australia [7,14] derived the TSP emission factor equation as $344A^{0.8}M^{-1.9}D^{-1.8}$ kg/blast; where A the area blasted in m^2, D is the depth of blasthole (m) and M is the moisture content (%). For estimation of PM_{10}, it will be multiplied by a factor of 0.52.

2.3. Emission Factors for European Mines

EEA (European Environmental Agency) emission inventory guidebook [15] has stated that emission factors estimation for open dust sources for coal mines as given in the USEPA document AP-42 [6] can be used.

2.4. Emission Factors for Indian Mines

Chakraborty *et al.* [16] developed emission rates for various surface coal mining activities except blasting. Ghose [17] calculated emission factors for different operations of the surface coal mine but he has not reported dust emission for blasting.

2.4.1. Remarks from the Overview

It is found that different countries have adopted different emission factors for blasting. Some empirical equations for emission factor include only area of blasts while other use area of blast, blasthole depth and moisture content. In most of the cases, emission factors have been expressed in pound per blasts or kilogram per blasts or in kilogram per tonne of the explosive used. No emission factors for blasting have been developed for Indian mines.

Coal or overburden benches in the mine cover different area of blasts as well as different blasthole depths depending on the requirements. After blasting, a volume of rock is broken and fragmented, which is the source of dust emission into the atmosphere. It would be better to develop emission factors in gram per cubic meter of rock excavated.

3. Blasting Dust Sampling Problems

The plume from a blast is particularly difficult to sample due to the vertical and horizontal dimensions of the plume and the inability to place sampling equipment near the blast [6]. To sample blasts, the exposure profiler concept was modified. Balloon-suspended samplers along with ground-based samplers were used for blasting dust monitoring, which was found to be impractical under field conditions. The location of the plume centerline depended very much on the exact wind direction at the time of the blast. Because the balloon sampling array required at least one hour to set up, it was impossible to anticipate the exact wind direction one hour in advance. Therefore, the ground-based samplers were placed at some distance apart when the wind was variable so that some of the samplers were in the plume. The balloon sometimes could not be moved to the plume centerline quickly enough after the blast. In order to avoid equipment damage from the blast debris and to obtain a representative sample of the plume, the balloon-suspended samplers were located 100 m downwind of the blast area. This distance varied depending on the size of the blast and physical constraints. These descriptions are given in Section 3 of USEPA report [6]. Potential errors like maintaining an isokinetic flow rate also occurred during sampling. Balloon sampling being a substantial modifycation of the exposure profiling method reveals somewhat experimental technique. Hence it was difficult to apply to blasting because technical limitations of the technique combined with the infrequency of blasting resulted in very few opportunities to perform the sampling. This sampling method could not be used when ground level winds were greater than about 6 m/s because the balloon could not be controlled on its tether. Sometimes balloon was found to be damaged due to blast debris. Because of logistical difficulties in sampler deployment, further field studies were not recommended.

It is observed that even after modification of sampling methodology, many problems occurred. No suitable method has been finalized for blasting dust monitoring. Sampling of blasting dust has been considered as a difficult source of field testing.

4. Description of Mine Sites

Field investigations were carried out at two large opencast coal mines. The first mine is Dudhichua project, Northern Coalfields Limited (NCL), Singrauli, Madhya Pradesh, India. It is one of the largest opencast coal mines of India and is surrounded by large opencast coal mines namely Jhingurdha, Bina, Jayant, Amlohri, Nigahi, Khadia, Block B and Krishnashila. These mines coming under Singrauli coalfield are divided into two basins viz. Moher sub-basin and Singrauli main basin. The present coal mining activities of NCL are concentrated in Moher sub-basin of 100 km^2. All the coal seams are common for all the mines of NCL except Jhingurdha seam which exists only in the Jhingurdha mine. In NCL, total coal production was 63.65 Mt and overburden removal was 203 million m^3 during 2008-09. Among them Dudhichua project produced 13.27 Mt coal and removed 34.36 million m^3 overburden using 18990 t explosive. This project is having an area of 8.68 km^2 and located in the central part of Moher basin of Singrauli Coalfields. The mine is situated between latitudes 24°7’30” and 24°10’ north and longitudes 82°40’ and 82°42’30” east. The area is undulating with an average elevation of 325 m above MSL. It is at a distance of 63 km by road from Renukut in Uttar Pradesh and 18 km from Singrauli railway station in Madhya Pradesh. The general strike in Dudhichua block is NW-SE and the dips are 1 in 20 to 1 in 25 (2 to 3°) towards north-east. The lithology consists of mainly soil, sandstone and coal. This mine was developed in ten benches including three in coal and seven in overburden. Large blasts are regularly conducted both in coal and overburden benches using huge quantities of explosives, thus increasing the potential for dust hazards in and around the mine. The main mining and transport equipment are electric shovels, draglines, dumpers, dozers, etc.

The second surface mine where field investigations were conducted is Bharatpur opencast project. It is one of the largest opencast coal mines of Mahanadi Coalfields Limited (MCL) and is located in Angul district of Talcher coalfields, Orissa, India. The mine is surrounded by different opencast coal mines. It produced 11.02 Mt coal in the year 2008-09 and removed 6.21 Mm^3 of overburden using 3824 t explosive. It is having an area of 6.81 km^2 and located in the south central part of the Talcher Coalfields. The mine is situated between latitudes 20°56’35” and 20°58’40” north and longitudes 85°06’30” and 85°08’40” east. The area is gently undulating with elevation from 92 m to 124 m above MSL. It is at a distance of 9 km, 12 km and 15 km by road from Talcher town, Talcher railway station and Angul town respectively. The general strike of the block is E-W and the beds dip 2° to 10° towards north. The lithology consists of mainly soil, sandstone and coal. The mine forms benches in coal and overburden for excavation. Large bench blasts being conducted both in coal and overburden increases likelihood of dust pollution surrounding the mine. The mining machinery deployed in this mine were similar to those of Dudhichua project.

5. Methodology

In surface mines, heavy bench blasting was conducted for excavation of overburden and production of coal. As the dust dissipates with distance, the dust generated due to blasting should be monitored surrounding the blast location. Usually the site conditions make blasting dust monitoring difficult because the benches to be blasted had high wall on one side and undulating or plane ground on the other side. Therefore, it was required to select a plane surface along one side of the blast location so that monitoring could be done by installing the dust samplers in the downwind direction. Samplers could not be installed on the high wall side when the wind was blowing in that direction.

Sometimes coal bench had no suitable locations but overburden had suitable locations for dust monitoring. All these practical problems caused variation in the number of data collected for coal and overburden benches.

After the complete survey of the mine, suitable sites surrounding the bench to be blasted were selected for blasting dust monitoring during post-monsoon (October-November), winter (January-February), summer (April-May) and monsoon (August-September) at Dudhichua project. Since the bench and blast parameters may vary from season to season, particulate matter can also vary. Therefore study was carried out in each season to obtain different seasonal value. Moisture content of the benches and the distances of sampling points from blast locations were determined in each season. These parameters corresponded to blasting dust monitored benches.

At Bharatpur opencast project, dust monitoring was conducted during post-monsoon (October-November) and winter (January) seasons to assess whether emission factors developed for Dudhichua project can be used for Bharatpur opencast project. Since suitability of emission factor had to be examined, therefore, one high polluting season and another less polluting season were considered for data collection at this project. Winter season being the worst possible scenario of air pollution, Chakraborty *et al.* [16] studied emission rates for various mining activities only in this season. Chaulya [18] also observed maximum particulate matter concentrations in winter. In both the seasons, only coal benches were monitored. Overburden benches were not monitored because the site conditions were not suitable for dust sampling.

5.1. Moisture Content Determination

Moisture content is the ratio of the weight of water to the weight of dry materials. It is expressed in percentage. Samples of drill cuttings were collected and moisture contents were determined at Coal Analysis Laboratory of the mines. Moisture content is determined for coal and overburden prior to blasting [6]. Moisture content has restraining nature in dust generation and may vary from season to season. Therefore, assessment of moisture content was carried out in each season.

5.2. Collection of Blast Details

Blast details such as number of blastholes, blasthole depth, burden, and spacing for coal and overburden benches for each season was used for evaluation of the volume of material blasted. The period during which blasts were carried out was also noted because stability classes and wind speed were required for calculation of emission factor for each blast for the corresponding period. The details corresponded to dust monitored benches.

5.2.1. At Dudhichua Project

In post-monsoon, 20 blasts were conducted, out of which 17 blasts were carried out during 13:00-14:00 and remaining during 14:00-15:00. In this season, 11 blasts were monitored in coal and 9 blasts in overburden benches. Only one coal bench was blasted frequently and monitored in this season. For this coal bench, blasthole depth for most of the blasts was 7.0 m to 7.5 m. Burden was 7 m for all the blasts. Spacing was either 7 m or 8 m. In case of overburden, blasts were conducted in different benches. The blasthole depth varied from 12 m to 19 m. Burden was from 6 m to 8 m and spacing was 6 m or 9 m.

In winter, all the 20 blasts were conducted during 13:00-14:00. Out of 20, 16 blasts were carried out in coal and 4 blasts in overburden benches. The blasthole depth varied from 7.0 m to 14.0 m in coal whereas from 10.5 m to 18 m in overburden. Burden was either 6 m or 7 m in coal and 8 m or 9 m in overburden. Spacing varied from 7.0 m to 8 m for coal and from 9 m to 10 m in overburden.

In summer, out of 16 blasts, 2 blasts were conducted during 14:00-15:00 and all others during 13:00-14:00. In this season, 12 blasts were monitored in coal and 4 blasts in overburden. In the coal, blasthole depth varied from 6.0 m to 13.0 m. Burden ranged from 3 m to 9 m or spacing from 3 m to 9 m. In the overburden, blasthole depth increased from 15.5 m to 20.0 m depending on the height of the benches. Burden varied from 8 m to 10 m while spacing was 9 m or 10 m.

In monsoon, all the 12 blasts were conducted during 13:00-14:00. Out of 12, 5 blasts were carried out in coal and 7 blasts in overburden. In coal, blasthole depth varied from 11 m to 12 m. Burden and spacing was either 7 m or 8 m. In the overburden, blasthole depth varied from 15 m to 18 m. Burden ranged from 8 m to 10 m while spacing was 9 m to 10 m.

5.2.2. At Bharatpur Opencast Project

In post-monsoon, out of 10 blasts, 6 blasts were carried out during 13:00-14:00 and remaining during 14:00-15:00. All the blasts were monitored in coal seam-IV, which was blasted by constructing three benches of 7 m, 7 m and 3 m high. Only this bench was suitable for dust monitoring. Blasthole depths varied from 3 m to 7 m. Burden and spacing varied from 3 m to 5 m.

In winter, blasts were conducted during different periods. Out of 10 blasts, 3 were conducted during 13:00-14:00, 6 blasts during 14:00-15:00 and one during 15:00-16:00. Only coal seam-II was a suitable site for blasting dust monitoring. Five benches were constructed in this seam, among them only three benches were frequently blasted and monitored. Blasthole depth of the benches varied from 5 m to 8 m. Burden was either 4 m or 4.5 m. Spacing varied from 4 m to 5 m.

5.3. Description of Dust Samplers

Respirable dust samplers, Instrumex IPM 115BL, were used for measurement of particulate matter, both TSP and PM_{10}. This dust sampler utilises a two-stage collection system for fractionating the particulate matter sizes. The first stage consists of a cyclone through which the particles greater than 10 μm sizes are separated from the air stream by centrifugal forces acting on the solid particles. The separated particulate falls through the cyclone's conical hopper and is collected in the plastic cup placed at its bottom [19]. PM_{10} is collected from the ambient air in the second stage by filtering the air stream through the glass microfibre filter. TSP consisted of both PM_{10} and the particles greater than 10 μm size. Whatman GF/A filter papers of 203 mm × 254 mm size were used for collection of PM_{10} and plastic cups for the particulate matter greater than 10 μm size. The filter papers were conditioned and desiccated [20] before and after sampling. For determination of particulate matter mass, initial and final weight of plastic cups and filter papers were taken using 235S Sartorius balance with sensitivity of 0.00001g. The flow rate of sampler was kept greater than 1.1 m^3/min. The concentration of the particulate matter was obtained from the difference (in micrograms) of the final weight of filter papers exposed minus the initial weight before exposure, divided by the sampled air volume (in cubic meter) [20,21].

5.3.1. Procedure for Dust Sampling

For particulate monitoring in an industrial area, often respirable dust samplers are operated either in three shifts of eight hours duration or continuously for twenty four hours at fixed locations. In case of blasting dust monitoring, it is not possible to keep the samplers at a fixed location because blast location changes time to time. Also monitoring cannot be done for hours because the dust emitted by blasting is dispersed quickly into the atmosphere. For the monitoring of dust, the sampler needs 230 V power supply for maintaining the flow rates greater than 1.1 m^3/min. In the mine, high voltage power of 6600 V was supplied by the main station through electric cables for the operation of heavy duty machineries such as drill machines, shovels, and draglines. As high voltage power could not be used for respirable dust samplers, 230 V power was taken only through the sockets of 230 V available inside the cabins of heavy duty machineries. For the safety point of view, sometimes high voltage power cable was disconnected from the heavy duty machineries. Hence samplers could not be operated. Alternative source of power supply was not available near the blast bench. To overcome this problem, a petrol generator was also used for the operation of samplers depending on the site condition. Since the amount of dust collected by the samplers depends on the wind direction, the samplers once installed in the downwind direction could not be reinstalled due to deviation in wind direction at the time of blasting. Mud, water logged area around the blasting site and rain interfered the dust monitoring in monsoon.

Dust samplers were installed at safe distances from the blast site in the downwind direction. The safe distance or distance depended on the size of blasts and on site condition. Also, installation of the samplers at a large distance was not suitable because the blasting dust would get mixed with the ambient air and hence it would be difficult to identify the contribution of dust by the blasting. Before installation, many blasts were observed for the accumulation period of dust in the downwind direction and accordingly 20 minutes monitoring periods were considered for sampling. After this period, the emitted dust was dispersed completely into the atmosphere. During the blasting period, all other mining activities were stopped, which is the usual practice for blast site clearance. Therefore, blasting dust monitoring was not affected by the other activities. The number of samplers installed depended on the site conditions. They were installed either approximately parallel to blast locations or at an increasing distance from the blast. All the partial or non collection of particulate matter data due to change of wind direction, getting the samplers tripped during monitoring period, etc were discarded.

To assess the background dust concentrations, samplers were operated for a duration of 20 minutes. The dust collected was negligible. Hence the influence of background dust concentrations was ignored for analysis.

5.4. Evaluation of Stability Classes Using Sodar

The details of sodar, installation and data generation for Dudhichua project are presented in report [22]. Sodar was operated continuously for 24-hours in post-monsoon, winter, summer, and monsoon seasons at Dudhichua project. In this analysis, stability classes, evaluated only for blasting dust monitoring period was used.

After completing the study at Dudhichua project, tri-axis monostatic (back-scattering) sodar was transported to Bharatpur opencast project and installed on the roof of an office building. Sodar was operated continuously for 24-hours in post-monsoon and winter at this site and stability classes were determined using sodar data for the blasting dust monitoring period for these seasons.

5.5. Monitoring of Meteorological Parameters

The details of automatic weather station, installation and results for Dudhichua project are presented in report [22]. The weather station was operated continuously for 24-hours in post-monsoon, winter, summer, and monsoon at Dudhichua project. But for the analysis, the data on wind speed recorded during blasting dust monitoring period at the mine site was used.

The same weather station was used at Bharatpur opencast project. It was installed on the roof of an office building adjacent to sodar. The weather station recorded data continuously for 24-hours in post-monsoon and winter. Wind speed data recorded during blasting dust monitoring period were used for analysis.

6. Results and Discussion

6.1. Particulate Matter Concentrations

For Dudhichua project, particulate matters for coal and overburden blasts at different locations in different seasons are given in **Tables 1** to **4**. These tables include a total of 20 blasts at 37 locations in post-monsoon (**Table 1**), 20 blasts at 52 locations in winter (**Table 2**), 16 blasts at 32 locations (**Table 3**) in summer and 12 blasts in monsoon at 30 locations (**Table 4**).

At Bharatpur opencast project, a total of 10 blasts at 19 locations in post-monsoon (**Table 5**) and 10 blasts at 20 locations (**Table 6**) in winter were monitored in coal. The values of particulate concentrations are also mentioned in these tables.

6.2. Determination of Stability Classes Using Mixing Height and Sodar Echograms

The details on mixing height and sodar echograms used for determination of stability classes at Dudhichua project for each season are presented in report [22]. The stability classes corresponding to the blasting dust monitoring period at Dudhichua project are given in **Tables 1** to **4**. Similarly, stability classes determined for the blasting dust monitoring period for two seasons at Bharatpur opencast project are shown in **Tables 5** to **6**.

To assess the similarity in stability classes for both the mine sites, percentage of atmospheric stability classes was calculated in respective seasons. In post-monsoon, only stability class A was observed to be 100% at the each mine site. In winter, class A was 95% and B was 5% at Dudhichua project whereas class A occurred 90% and B 10% at Bharatpur opencast project indicating that there were some differences in stability classes at the mine sites in this season.

6.3. Dispersion Coefficients

Two sets of dispersion coefficients are used in the Gaussian plume models. The lateral dispersion coefficient (σ_y) represents the horizontal spread of the plume perpendicular to the direction of travel. The vertical dispersion coefficient (σ_z) represents the spread of the plume in the

Table 1. Emission factors for coal and overburden in post-monsoon at Dudhichua project, NCL.

Blast no.	Date of blasting	Blasting schedule	No. of dust samplers	Distance (m)	Stab. class	Wind speed (m/s)	Dispersion coefficient (m)		Particulate matter (μg/m^3)		Calculated emission factor (g/m^3)		Volume of rock excavated (m^3)	Moisture content (%)	Rock type
							σ_y	σ_z	PM_{10}	TSP	PM_{10}	TSP			
1	21.10.08	14:00-15:00	1	85	A	0.75	25	17	2730	11919	0.49	2.13	6720	13.97	Coal
2	23.10.08	13:00-14:00	1	90	A	0.90	25	17	508	3318	0.07	0.46	10500	13.97	Coal
3	25.10.08	13:00-14:00	1	135	A	1.08	34	22	262	1357	0.05	0.27	15120	4.68	OB
				40			25	17	1191	9964					
4	26.10.08	14:00-15:00	3	35	A	1.71	25	17	2914	21613	0.17	1.53	41328	3.53	OB
				35			25	17	3742	37467					
5	29.10.08	13:00-14:00	2	30	A	0.77	25	17	3684	22237	0.28	1.79	19836	4.68	OB
				35			25	17	5380	35295					
6	31.10.08	13:00-14:00	2	150	A	2.21	38	21	1606	10039	0.23	1.41	54720	4.29	OB
				130			33	21	2515	15168					
7	01.11.08	13:00-14:00	1	80	A	1.07	25	17	2251	14986	1.12	7.43	3456	3.78	OB
8	02.11.08	13:00 - 14:00	1	31	A	1.22	25	17	1118	7692	0.59	4.09	3675	13.97	Coal
9	04.11.08	14:00-15:00	2	35	A	0.19	25	17	567	5126	0.02	0.16	7718	13.97	Coal
				70			25	17	658	2932					
10	06.11.08	13:00-14:00	2	70	A	0.62	25	17	690	5634	0.17	1.45	4043	13.97	Coal
				30			25	17	721	6167					
				75			25	17	781	3437					
11	10.11.08	13:00-14:00	3	35	A	1.15	25	17	624	2047	0.38	1.49	4410	13.97	Coal
				35			25	17	1332	5192					
12	13.11.08	13:00-14:00	1	90	A	0.56	25	17	2240	15220	0.69	4.65	2940	13.97	Coal
				130			33	21	502	3629					
13	14.11.08	13:00-14:00	3	140	A	1.35	35	22	905	3057	0.43	1.83	6248	13.97	Coal
				155			39	24	566	1993					
				35			25	17	1517	8073					
14	15.11.08	13:00-14:00	3	35	A	0.57	25	17	1896	11389	0.31	1.72	4752	3.53	OB
				35			25	17	1473	7391					
15	16.11.08	13:00-14:00	1	85	A	0.66	25	17	2248	10136	0.22	0.97	11025	13.97	Coal
				95			25	17	515	2288					
16	17.11.08	13:00-14:00	3	95	A	0.18	25	17	973	4832	0.03	0.13	10633	13.97	Coal
				95			25	17	1755	7686					
17	18.11.08	13:00-14:00	1	130	A	0.61	33	21	3286	6259	0.28	0.52	19008	3.53	OB
18	19.11.08	13:00 - 14:00	2	100	A	0.62	25	17	237	1458	0.06	0.25	5880	13.97	Coal
				100			25	17	422	1459					
				80			25	17	1812	12176					
19	21.11.08	13:00 - 14:00	3	80	A	0.54	25	17	2985	25182	0.41	3.01	4320	6.24	OB
				80			25	17	1291	7663					
20	22.11.08	13:00 - 14:00		70	A	0.61	25	17	1134	14240	0.17	2.15	6480	4.68	OB

***OB*: Overburden**

Table 2. Emission factors for coal and overburden in winter at Dudhichua project, NCL.

Blast no.	Date of blasting	Blasting schedule	No. of dust samplers	Distance (m)	Stab. class	Wind speed (m/s)	Dispersion coefficient (m)		Particulate matter (μg/m³)		Calculated emission factor (g/m³)		Volume of rock excavated (m³)	Moisture content (%)	Rock type
							σ_y	σ_z	PM_{10}	TSP	PM_{10}	TSP			
1	24.1.09	13:00-14:00	1	70	A	0.72	25	17	6321	38226	0.07	0.44	100440	7.55	OB
2	25.1.09	13:00-14:00	3	140	A	0.60	35	22	722	4640	0.08	0.47	17472	10.82	Coal
				140			35	22	912	5027					
				140			35	22	669	4364					
3	27.1.09	13:00-14:00	2	80	A	1.14	25	17	2183	17303	0.08	0.63	59472	3.63	OB
				80			25	17	2822	23599					
4	29.1.09	13:00-14:00	3	30	A	1.41	25	17	3787	31298	0.84	6.22	7923	15.5	Coal
				130			33	21	1677	9727					
				130			33	21	1391	11183					
5	31.1.09	13:00-14:00	3	100	A	1.13	25	17	556	3404	0.08	0.56	11648	10.82	Coal
				100			25	17	537	4565					
				100			25	17	474	2824					
6	01.2.09	13:00-14:00	3	150	A	0.55	38	24	172	1521	0.09	0.55	5600	10.82	Coal
				150			38	24	176	1156					
				150			38	24	472	2241					
7	05.2.09	13:00-14:00	2	60	A	0.53	25	17	12143	37757	0.10	0.33	104904	5.7	OB
				40			25	17	12890	43213					
8	07.2.09	13:00-14:00	3	40	A	1.32	25	17	2175	10079	0.91	5.97	5292	15.5	Coal
				40			25	17	3182	24699					
				40			25	17	1491	10010					
9	08.2.09	13:00-14:00	3	40	A	0.69	25	17	538	1955	0.21	1.15	4040	15.5	Coal
				30			25	17	1282	6130					
				30			25	17	461	4555					
10	09.2.09	13:00-14:00	3	20	A	0.67	25	17	1460	11021	0.30	1.92	5488	15.5	Coal
				20			25	17	1358	6677					
				20			25	17	1729	11727					
11	10.2.09	13:00-14:00	3	20	A	0.99	25	17	2014	11260	0.75	4.17	3175	15.5	Coal
				30			25	17	1335	6192					
				30			25	17	1175	7610					
12	12.2.09	13:00-14:00	3	30	A	1.03	25	17	807	2395	0.11	1.21	8114	15.5	Coal
				30			25	17	603	3349					
				30			25	17	234	12123					
13	13.2.09	13:00-14:00	2	30	A	0.86	25	17	1793	8309	0.14	0.70	15120	6.16	OB
				30			25	17	1303	7054					
14	14.2.09	13:00-14:00	3	30	A	0.68	25	17	1210	5647	0.19	1.16	5488	15.5	Coal
				30			25	17	920	4995					
				30			25	17	738	6849					
15	15.2.09	13:00-14:00	2	30	A	0.74	25	17	1161	6127	0.14	0.91	10584	15.5	Coal
				30			25	17	1365	10201					
16	17.2.09	13:00-14:00	3	100	A	0.46	25	17	283	2353	0.04	0.30	5513	15.5	Coal
				100			25	17	247	1628					
				100			25	17	284	2748					
17	18.2.09	13:00-14:00	3	20	A	0.47	25	17	1407	9505	0.21	1.17	7203	15.5	Coal
				20			25	17	3283	14019					
				30			25	17	1286	9963					
18	20.2.09	13:00-14:00	2	66	A	0.74	25	17	3277	13973	0.18	0.86	15092	10.82	Coal
				66			25	17	1239	8032					
19	21.2.09	13:00-14:00	3	16	B	0.46	18	12	2477	11990	0.06	0.41	11907	10.82	Coal
				16			18	12	2134	19831					
				29			18	12	1504	7755					
20	22.2.09	13:00-14:00	2	35	A	0.44	25	17	3913	12377	0.23	1.04	8008	10.82	Coal
				35			25	17	1420	11241					

OB*: *Overburden

Table 3. Emission factors for coal and overburden in summer at Dudhichua project, NCL.

Blast no.	Date of blasting	Blasting schedule	No. of dust samplers	Distance (m)	Stab. class	Wind speed (m/s)	Dispersion coefficient (m)		Particulate matter (μg/m³)		Calculated emission factor (g/m³)		Volume of rock excavated (m³)	Moisture content (%)	Rock type
							σ_y	σ_z	PM_{10}	*TSP*	PM_{10}	*TSP*			
1	27.4.09	13:00-14:00	2	150	B	1.91	26	17	545	5282	0.07	0.46	31185	6.78	OB
				150			26	17	857	3728					
2	04.5.09	13:00-14:00	1	150	A	1.38	38	24	1340	14215	0.16	1.68	40095	6.78	OB
3	07.5.09	13:00-14:00	2	100	A	1.95	25	17	1345	5378	0.65	4.06	8995	15.44	Coal
				40			25	17	2406	18015					
				80			18	12	5578	32684					
4	08.5.09	14:00-15:00	3	80	B	1.89	18	12	8421	34631	0.11	0.56	100000	4.87	OB
				80			18	12	7007	41335					
5	10.5.09	13:00-14:00	1	150	B	1.71	26	17	5730	15965	1.28	3.55	12800	14.19	Coal
				160			40	25	998	8431					
6	11.5.09	13:00-14:00	3	160	A	2.43	40	25	1302	8911	0.84	5.63	12000	14.19	Coal
				160			40	25	1005	4799					
				100			25	17	1564	12514					
7	12.5.09	13:00-14:00	3	100	A	0.90	25	17	1428	13300	0.30	2.27	6400	14.19	Coal
				100			25	17	1035	4423					
8	13.5.09	13:00-14:00	1	150	A	1.74	38	24	1949	10829	0.19	1.06	61380	6.12	OB
				60			25	17	1501	11830					
9	15.5.09	13:00-14:00	3	90	A	1.46	25	17	744	7286	0.39	2.82	8320	14.19	Coal
				150			38	24	916	5114					
10	16.5.09	14:00-15:00	1	60	A	1.20	25	17	2749	15868	0.41	2.38	12800	14.19	Coal
11	17.5.09	13:00-14:00	1	60	A	1.28	25	17	3333	13206	2.41	9.55	2835	13.91	Coal
12	18.5.09	13:00-14:00	2	55	A	1.75	25	17	3798	13938	0.60	2.48	13608	13.91	Coal
				55			25	17	1990	10131					
13	23.5.09	13:00-14:00	2	70	A	1.30	25	17	4197	15639	0.28	1.58	30576	14.19	Coal
				50			25	17	4065	30604					
14	24.5.09	13:00-14:00	1	150	A	0.42	38	24	999	8187	0.38	3.13	3780	15.44	Coal
				60			25	17	2262	11750					
15	25.5.09	13:00-14:00	3	60	A	2.04	25	17	2633	13709	0.43	2.60	20384	14.19	Coal
				60			25	17	3150	23155					
				80			25	17	969	3706					
16	27.5.09	13:00-14:00	3	80	A	1.49	25	17	1532	10907	0.60	4.01	4992	14.19	Coal
				80			25	17	1284	10521					

OB*: *Overburden

Table 4. Emission factors for coal and overburden in monsoon at Dudhichua project, NCL.

Blast no.	Date of blasting	Blasting schedule	No. of dust samplers	Distance (m)	Stab. class	Wind speed (m/s)	Dispersion coefficient (m)		Particulate matter (μg/m^3)		Calculated emission factor (g/m^3)		Volume of rock excavated (m^3)	Moisture content (%)	Rock type
							σ_y	σ_z	PM_{10}	TSP	PM_{10}	TSP			
				70			25	17	587	1876					
1	13.8.09	13:00-14:00	3	70	A	0.66	25	17	482	2208	0.09	0.42	6336	17.11	Coal
				70			25	17	554	3376					
2	15.8.09	13:00-14:00	2	90	A	0.49	25	17	371	2865	0.06	0.28	6468	17.11	Coal
				120			30	20	416	1251					
3	22.8.09	13:00-14:00	1	80	A	0.57	25	17	734	1723	0.03	0.06	27000	6.28	OB
				70			25	17	448	1030					
4	24.8.09	13:00-14:00	3	70	A	0.97	25	17	57	831	0.11	0.36	4851	17.11	Coal
				70			25	17	498	1509					
				60			25	17	407	2219					
5	25.8.09	13:00-14:00	3	60	A	1.07	25	17	424	813	0.12	0.37	5632	17.11	Coal
				60			25	17	378	602					
6	26.8.09	13:00-14:00	2	60	A	2.29	25	17	441	12542	0.04	0.63	38880	5.11	OB
				90			25	17	416	883					
7	30.8.09	13:00-14:00	2	100	A	0.88	25	17	526	1087	0.11	0.30	5760	6.28	OB
				100			25	17	399	1338					
				35			25	17	1532	8611					
8	01.9.09	13:00-14:00	3	42	A	0.38	25	17	2011	12342	0.11	0.73	9600	6.28	OB
				51			25	17	1867	13383					
				15			25	17	691	2940					
9	02.9.09	13:00-14:00	3	15	A	0.61	25	17	571	2374	0.11	0.56	5888	17.11	Coal
				15			25	17	741	4833					
				50			25	17	1397	5328					
10	09.9.09	13:00-14:00	3	50	A	0.62	25	17	738	2917	0.09	0.34	9600	6.28	OB
				50			25	17	607	1708					
11	10.9.09	13:00-14:00	2	50	B	0.46	18	12	864	2905	0.05	0.21	6800	6.28	OB
				50			18	12	848	4868					
12	12.9.09	13:00-14:00	2	70	A	0.57	25	17	598	2101	0.02	0.08	20400	6.28	OB
				70			25	17	400	1290					

OB*: *Overburden

Table 5. Emission factors for coal and overburden in post-monsoon at Bharatpur opencast project, MCL.

Blast no.	Date of blasting	Blasting schedule	No. of dust samplers	Distance (m)	Stab. class	Wind speed (m/s)	Dispersion coefficient (m)		Particulate matter (μg/m^3)		Calculated emission factor (g/m^3)		Volume of rock excavated (m^2)	Moisture content (%)	Rock type
							σ_y	σ_z	PM_{10}	TSP	PM_{10}	TSP			
1	29.10.09	14:00-15:00	1	21	A	0.17	25	17	2068	13546	0.10	0.67	5528	5.93	Coal
				30			25	17	1145	6466					
2	02.11.09	13:00-14:00	3	30	A	0.24	25	17	1776	12040	0.08	0.53	7350	9.96	Coal
				30			25	17	1403	12084					
3	03.11.09	13:00-14:00	1	30	A	2.46	25	17	731	5768	1.37	10.82	2100	5.93	Coal
				100			25	17	392	1543					
4	05.11.09	13:00-14:00	3	100	A	3.37	25	17	490	3890	1.51	9.54	1750	9.96	Coal
				100			25	17	581	3846					
				33			25	17	446	1530					
5	06.11.09	13:00-14:00	3	33	A	1.12	25	17	322	2398	0.25	1.44	2975	5.93	Coal
				33			25	17	497	3218					
6	08.11.09	14:00-15:00	2	100	A	1.79	25	17	142	477	0.16	0.73	3500	9.96	Coal
				100			25	17	237	1305					
7	09.11.09	13:00-14:00	2	56	A	0.27	25	17	254	1004	0.15	0.59	540	21.26	Coal
				56			25	17	118	459					
8	09.11.09	14:00-15:00	1	100	A	0.79	25	17	1043	7689	0.25	1.82	5355	5.93	Coal
9	10.11.09	13:00-14:00	2	100	A	1.95	25	17	285	2289	0.39	3.58	2552	9.96	Coal
				100			25	17	348	3566					
10	10.11.09	14:00-15:00	1	70	A	1.22	25	17	780	6190	0.32	2.56	4725	5.93	Coal

vertical direction [23]. For known stability classes, σ_y and σ_z as horizontal and vertical dispersion coefficients as a function of downwind distances from the source using Pasquill-Gifford curves [24] were determined using **Figures 1** and **2**. The dispersion coefficients for Dudhichua project are shown in **Tables 1** to **4**.

For known stability classes, for Bharatpur opencast project, the horizontal and vertical dispersion coefficients were also evaluated by **Figures 1** and **2**. The values of dispersion coefficients are shown in **Tables 5** and **6**.

6.4. Wind Speed

Wind speeds for the corresponding blasting period recorded at Dudhichua project are given in **Tables 1** to **4**. It can be seen that there were no significant seasonal variations in wind speed. Wind speeds monitored at Bharatpur opencast project are given in **Tables 5** and **6**.

To compare the wind speeds, average of wind speed at the mine sites was calculated for respective seasons. The average wind speed in post-monsoon at Dudhichua project and Bharatpur opencast project was 0.87 m/s and 1.34 m/s respectively. In winter, the average wind speed at Dudhichua project was 0.78 m/s and at Bharatpur opencast project was 0.83 m/s. No significant differences in wind speeds were observed at the mine sites during the concerned seasons.

6.5. Calculation of Emission Factors

For known dust concentrations, dispersion coefficients and wind speeds, emission rates for blasting were calculated using the following modified Pasquill and Gifford formula (1,25,26).

Table 6. Emission factors for coal and overburden in winter at Bharatpur opencast project, MCL.

Blast no.	Date of blasting	Blasting schedule	No. of dust samplers	Distance (m)	Stab. class	Wind speed (m/s)	Dispersion coefficient (m)		Particulate matter (μg/m³)		Calculated emission factor (g/m³)		Volume of rock excavated (m³)	Moisture content (%)	Rock type
							σ_y	σ_z	PM_{10}	TSP	PM_{10}	TSP			
1	08.01.10	14:00-15:00	2	40	A	0.96	25	17	1010	5093	0.91	3.44	2552	4.34	Coal
				40			25	17	2009	6314					
2	08.01.10	14:00-15:00	2	55	A	0.96	25	17	1053	6345	0.79	4.39	2126	3.25	Coal
				55			25	17	1132	5789					
3	09.01.10	13:00-14:00	2	44	A	0.89	25	17	1095	6935	1.16	7.35	1280	10.25	Coal
				44			25	17	986	6268					
4	10.01.10	14:00-15:00	2	25	A	0.61	25	17	1181	5996	0.78	4.23	1386	3.25	Coal
				25			25	17	1041	6012					
5	11.01.10	13:00-14:00	2	75	A	0.63	25	17	521	2661	0.17	0.77	2977	10.25	Coal
				75			25	17	521	2661					
6	11.01.10	14:00-15:00	2	100	A	1.37	25	17	238	971	0.19	1.11	2835	4.34	Coal
				80			25	17	262	1894					
7	11.01.10	14:00-15:00	2	40	A	1.37	25	17	3536	12326	1.22	4.01	6480	3.25	Coal
				40			25	17	3638	11368					
8	12.01.10	13:00-14:00	2	55	A	0.56	25	17	1258	5325	0.36	1.81	2520	3.25	Coal
				70			25	17	751	4826					
9	13.01.10	14:00-15:00	2	60	A	0.78	25	17	722	2049	0.65	2.58	1188	10.25	Coal
				60			25	17	518	2860					
10	14.01.10	15:00-16:00	2	35	B	0.18	18	12	741	2430	0.07	0.23	1448	10.25	Coal
				35			18	12	658	2124					

$$C_{x,0} = \frac{Q}{\pi u \sigma_y \sigma_z} \quad (1)$$

where $C_{x,0}$ is the pollutant concentration (g/m³), Q is the pollutant emission rate (g/s), n = 3.14159, u is the mean wind speed (m/s), σ_y is the horizontal dispersion coefficient, σ_z is the vertical dispersion coefficient.

TSP and PM_{10} values for different seasons indicated pollutant concentrations ($C_{x,0}$) in (1). Blasting was considered as volume source and hence emission factors were calculated in gram per cubic meter of the rock excavated. Emission factors for different blasts for different seasons for Dudhichua project are given in **Tables 1** to **4**.

The statistics of emission factors for coal and overburden for all the seasons is shown in **Table 7**. It is observed that the average emission factor for PM_{10} and TSP in coal blasts is higher than that for overburden blasts, indicating that per cubic meter of coal bench blasted emits more dust into the atmosphere than overburden. This may be explained by the higher in-situ percentage of dust in coal compared to overburden.

The emission factors for all the blasts of Bharatpur opencast project were also calculated for post-monsoon and winter using the procedures as followed for Dudhichua project. The emission factors for the Bharatpur opencast project are shown in **Tables 5** and **6**. Some variations were found in the emission factors when compared for the respective seasons of the mines indicating

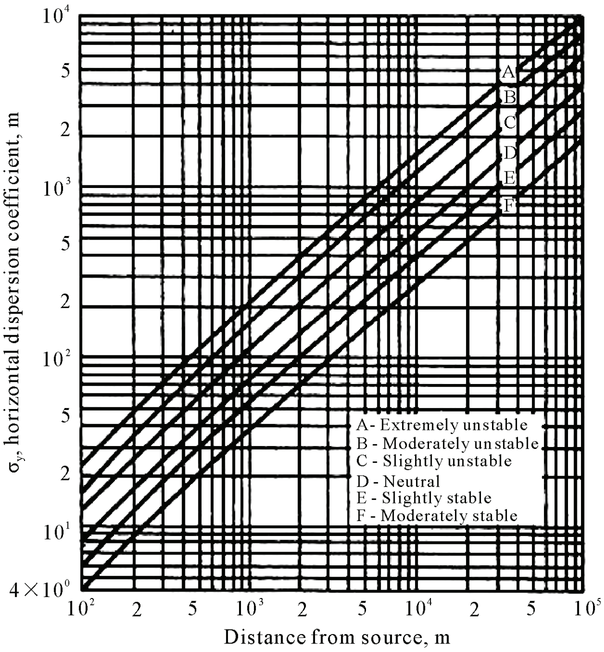

Figure 1. Horizontal dispersion coefficient σ_y vs downward distance from source.

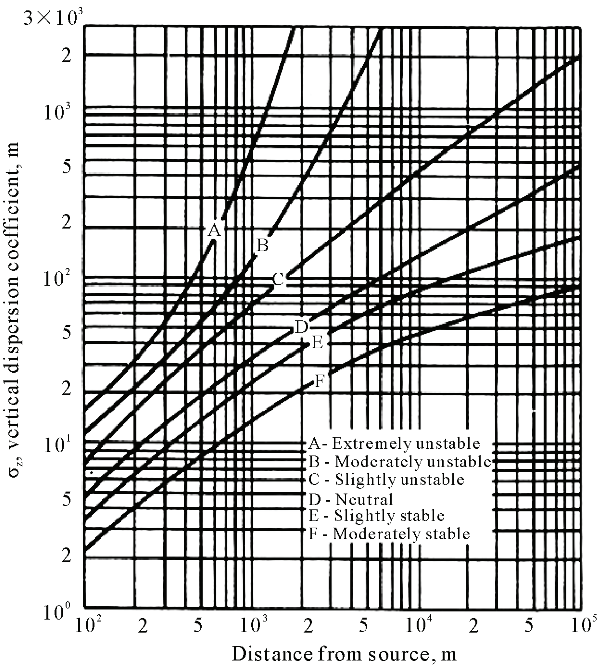

Figure 2. Vertical dispersion coefficient σ_z vs downward distance from source.

that emission factors are site-specific.

6.5.1. Influence of Moisture Content on Emission Factors

Since the moisture content in mine benches vary from season to season, the calculated PM_{10} and TSP emission factors in different seasons for different blasts were plotted for all the data (**Figures 3 (a), (b)**). Emission factors for PM_{10} and TSP are higher in summer and the lowest in monsoon indicating higher dust emission in summer. The presence of higher moisture content in monsoon might be the reason for decrease in emission factor in this season. The particulate emissions depend on the moisture content of the material blasted [3,6]. The emissions are lower when the moisture content is higher and vice versa. Though there is no control method or emission reduction technique for blasting in coal and overburden [7], moisture content influenced the emissions of blasting dust.

Table 7. Emission factors for coal and overburden for Dudhichua project, NCL.

Statistics	Emission factor (g/m^3)			
	Coal		*Overburden*	
	TSP	PM_{10}	TSP	PM_{10}
Minimum	0.13	0.02	0.06	0.02
Maximum	9.55	2.41	7.43	1.12
Mean	2.08	0.38	1.17	0.18
Standard deviation	2.04	0.43	1.53	0.22

6.5.2. Frequency Distribution of Emission Factors

Histograms with normal distribution curve of PM_{10} and TSP emission factors were plotted by combined data sets of 68 blasts including coal and overburden (**Figures 4(a), (b)**) using SPPS software version 13.0. For PM_{10} emission factor, frequency was the highest for the range of 0.02-0.25 g/m^3 and for TSP, the highest frequency occurred for the range 0.06-1.00 g/m^3 indicating that maximum number of emission factors occurred in this range.

The emission factor values are normally distributed in positive direction. Most of the areas of histograms are under normal distribution curve. According to McClave and Sincich [27], histograms display the frequency of the measurements falling into specified intervals. The normal distribution plays a very important role in the science of statistical inference. Its physical appearance is that of a symmetrical bell-shaped curve, a histogram is said to be approximately normal when the areas of the rectangles are approximately equal to corresponding areas under a normal curve [28].

7. Application of Emission Factor for Quantification of Blasting Dust

Each mine of NCL regularly conducts more than two large blasts everyday for excavation of coal or overbur-

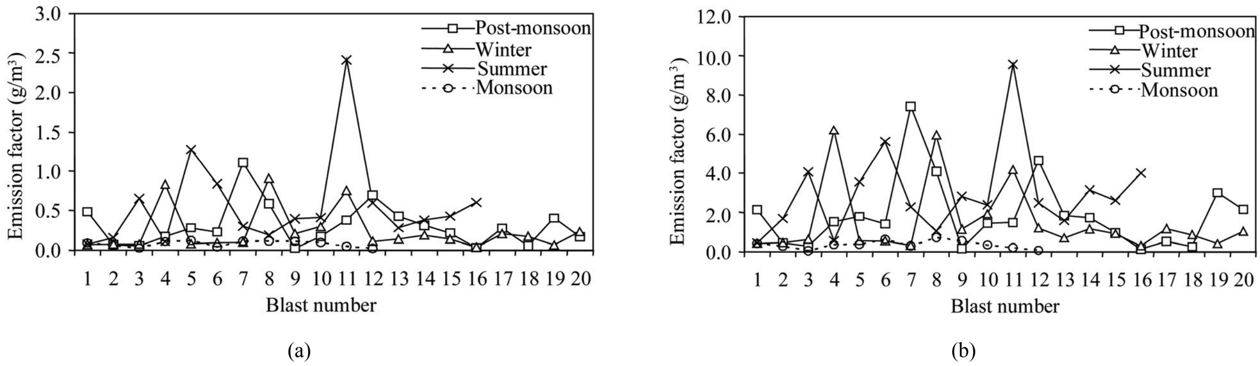

Figure 3. (a) Seasonal variations in emission factors of PM_{10} at Dudhichua project; (b) Seasonal variations in emission factors of TSP at Dudhichua project.

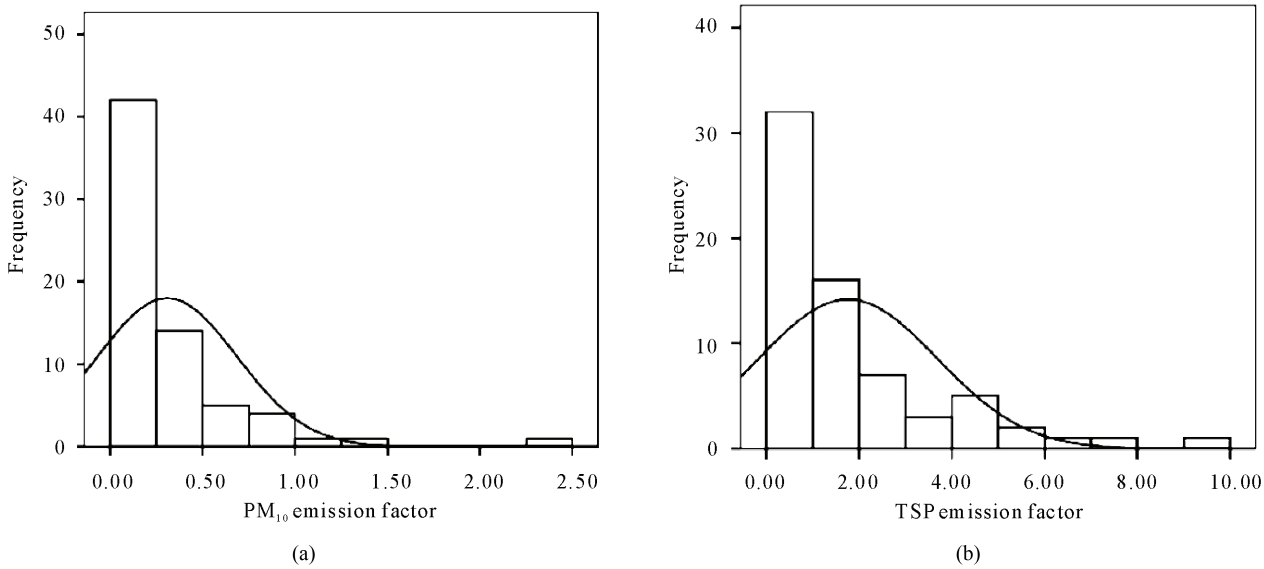

Figure 4. (a) Histograms with normal distribution curve for PM_{10} emission factors at Dudhichua project; (b)Histograms with normal distribution curve for TSP emission factors at Dudhichua project.

den removal. The excavated materials during 2008-09 revealed that thousands of blasts were conducted in the mines (**Table 8**). As a result, huge amount of dust would have emitted into the atmosphere and would have depleted the air quality in and around the mining area. It would certainly be interesting to quantify the dust generated by blasting. Once the amount of dust generation is ascertained, the impact on air environment can be evaluated and proper mitigative measures would be thought of for control of dust pollution caused by blasting in the area. The quantification of blasting dust can be done by the emission factor. At Dudhichua project, the average emission factor for coal was 0.38 g/m^3 and 2.08 g/m^3 for PM_{10} and TSP respectively. For overburden benches, these were 0.18 g/m^3 and 1.17 g/m^3 for PM_{10} and TSP respectively. Since mining, geological conditions and meteorological parameters of this area are identical; these emission factors can be used to quantify the dust generated for known volume of overburden and coal. According to USEPA [1] and Cole and Kerch [3], a mine-specific emission factor can be used only if the characteristics of the mine for which emission estimate is needed are very similar to those of the mine for which the emission factor was developed. Using the emission factors, the quantity of dust emitted during 2008-09 were calculated for the volume of rock excavated during this period (**Table 8**). From this table, it is clear that huge amount of dust were emitted during production of coal and removal of overburden. This calculated dust emission can help the mining officials to know which of the mines generated high dust into the atmosphere and accordingly they could adopt control measures for high dust emitting mines. Considering that NCL is planning to increase production, the dust emission will certainly increase in future unless

Table 8. Calculated particulate emissions for coal production and overburden removal at different mines of NCL during 2008-09.

Name of the mine	Coal production (million m^3)	Particulate emissions (kg)		Overburden removal (million m^3)	Particulate emissions (kg)	
		PM_{10}	*TSP*		PM_{10}	*TSP*
Jhingurdha	2.38	904	4950	4.56	821	5335
Bina	3.36	1277	6989	27.16	4889	31777
Jayant	8.04	3055	16723	25.83	4649	30221
Kakri	1.81	688	3765	12.13	2183	14192
Dudhichua	8.19	3112	17035	34.36	6185	40201
Amlohri	3.26	1239	6781	24.02	4324	28103
Nigahi	7.20	2736	14976	39.41	7094	46110
Khadia	2.27	863	4722	15.64	2815	18299
Block B	2.12	806	4410	9.17	1651	10729
Krishnashila	0.67	255	1394	10.48	1886	12262
Total	**39.30**	**14934**	**81744**	**203**	**36497**	**237229**

dust control measures are adopted. The emission factors can be used by mining officials to determine the expected annual emissions, which can be used to categorize the mines generating high or low dust due to blasting operation. The emission factors provide engineers, planners, and regulators with a tool for assessing the potential environmental impacts of planned or existing blasting dust emission so that control efforts can be applied in a cost-effective manner. Hence the computed emission factors have an immense significance in the field of environmental protection. The developed emission factor for blasting dust can also be used during EIA study and hence preparation of EMP.

8. Conclusions

- For the conditions of Dudhichua project, the average emission factor for coal was 0.38 g/m^3 for PM_{10} and 2.08 g/m^3 for TSP. For overburden, the average emission factor was observed to be 0.18 g/m^3 and 1.17 g/m^3 for PM_{10} and TSP respectively. These values can be used to estimate the emission quantities generated due to blasting.
- Seasonal variation in emission factors indicated that the emission factor was the lowest in monsoon due to higher moisture content in this season.
- As all the mines of NCL are located adjacent to each other and mining and meteorological conditions are identical, emission factors developed for Dudhichua project can also be applied for all the adjacent mines.
- The emission factors for Bharatpur opencast project for post-monsoon and winter seasons were compared with those for Dudhichua project, which shows that emission factors are site-specific, unless geo-mining and meteorological conditions are identical.

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