PREDICTION OF DUST DISPERSION FROM DRILLING OPERATION IN SURFACE MINES

Thesis

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

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OCTOBER, 2016

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DECLARATION

I hereby *declare* that the Research Thesis entitled **“Prediction of Dust Dispersion from Drilling Operation in Surface Mines”** which is being submitted to the **National Institute of Technology Karnataka, Surathkal,** in partial fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy** in **Mining Engineering,** is a *bonafide report of the research work carried out by me*. The material contained in this Research Thesis has not been submitted to any University or Institution for the award of any degree.

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CERTIFICATE

This is to certify that the Research Thesis entitled **"Prediction of Dust Dispersion from Drilling Operation in Surface Mines"** submitted by **Mr. K.V. Nagesha**, (Register Number: **135003MN13P02**) as the record of the Research work carried out by him, is accepted as the Research Thesis submission in partial fulfillment of the requirements for the award of degree of **Doctor of Philosophy**.

Dr. K. Ram Chandar & Prof. V. R. Sastry
Research Guide(s)

Prof. M. Govinda Raj
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ACKNOWLEDGEMENTS

The more various one's obligations are, the harder it is to describe them satisfactorily or to be sure of their extent. Throughout the duration of doctorate programme, I had access to invaluable guidance. Adequate acknowledgments are obviously impossible.

I am deeply indebted to my research guide Dr. K. Ram Chandar, Asst. Professor Department of Mining Engineering, NITK, Surathkal, for providing me an opportunity to work under his guidance. His thorough and keen insight into the subject has provided me with many instant solutions to the problems. He encountered and thus helped me to smoothly progress towards my goal. No word will be adequate to quantify his patience, tolerance and understanding. He has been a constant source of inspiration in all possible ways for successful completion of my Ph.D.

I am deeply indebted to my additional research guide, Prof. V.R. Sastry, Department of Mining Engineering, NITK, Surathkal, for his invaluable guidance and constant encouragement. He is a constant source of Knowledge. His detailed and generously constructive comments helped me to bring out the research work in the present form successfully.

My thanks goes to Prof. M. Govinda Raj, Head of the Department, Department of Mining Engineering, NITK, Surathkal, for providing the Departmental facilities during the course of work.

I acknowledge my sincere gratitude to Dr. G.C. Mohan Kumar, Professor, Department of Mechanical Engineering, NITK, Surathkal, RPAC member, who gave informative and valuable suggestions for my research work.

I acknowledge my sincere gratitude to Dr. M. Aruna, Associate Professor, Department of Mining Engineering, NITK, Surathkal, RPAC member, who gave valuable suggestions for my research work.

I would like to express my special thanks to all the faculty members and supporting staff of the Department of Mining Engineering, NITK, Surathkal, who helped me in one way or the other during my research work. I extend my gratitude to the authorities of NITK, Surathkal, and staff of Department of Mining Engineering for the help provided during the course of work.

My hearty thanks to my friends Kumar Dorthi and G. Raghu Chandra, Research Scholars, Department of Mining Engineering, NITK, Surathkal, who have helped me in many ways during my research course.

My very special thanks to my parents for making me what I am today. I thank my Late My Father and My Mother for showing me the power of love and most all, for being a role model in perseverance. My wonderful sisters and brothers, thanks for your support and making me feel special.

I sincerely express my heartfelt thanks to all my friends, who have helped me directly or indirectly during this Ph.D. work. I also express my sincere gratitude to all those who constantly provided me necessary information and facilities throughout the period of my thesis work.

I thank the authorities of mines and quarries who have permitted me to collect the data from various mines and quarries.

K.V. Nagesha

ABSTRACT

Dust pollution causes various problems within and outside the mine environment. Dust emanating from different activities directly affects the people working in the mines. Dust deposition on Heavy Earth Moving Machinery (HEMM) and other machinery can damage the machinery. The various activities involved in mining to extract ore from earth lead to dust pollution. Especially, Particulates Matters (PM) present in mines area lead to various human respiratory diseases. Aerodynamic diameter of particles having less than 10µm called as PM10. Among all activities involved in mining, drilling activity is more important and it produces PM particles. Dust prediction models are necessary to identify the quantity of dust expected from drilling so that dust control strategies can be taken up at mine site.

In order to develop dust prediction models in surface mines, field investigations were carried out in eight opencast mines. Among them, three are opencast coal mines, two are limestone mines and the remaining are granite quarries. Two opencast mines, two granite quarries and one limestone mine data was used to develop mathematical models. One coal mine data, one granite quarry data and one limestone mine data was used to validate developed models. To develop dust prediction models, 169 sets of data for emission model and 184 sets of data for concentration model from different rock formations were considered. Field monitoring was carried out according to Central Pollution Control Board (CPCB) standards. Rock samples were collected from different locations of mines and brought to the laboratory for determining required physico-mechanical properties according to International Society for Rock Mechanics (ISRM) suggested methods. Various rock properties considered are Moisture content, Density, Compressive strength and Schmidt rebound hardness number.

Artificial Neural Network (ANN) analysis was carried out for different combinations of hidden layers. Feed Forward Neural Network with back–propagation algorithm was used to train the network. Four types of algorithms were used for development of models and their performances were evaluated using Values Account For (VAF), Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). Network was trained using different types of Back-propagation algorithms such as Trainrp, Trainscg, Traincgp, Trainlm. The algorithm ‘Trainlm’ has high MAPE and less RMSE. Value of RMSE is 6.68, MAPE value is 33 and VAF value is 79.90. Trainlm algorithm was found to be the best method for prediction of PM10 from drilling operation and was used for comparison.

The predicted values from ANN method and field measured values were compared. The R^2 value for emission model is 0.81 and for concentration model it is 0.80, which shows very good correlation and gave better forecasting results using ANN method. Analysis showed that the field data is error free. But, ANN cannot give mathematical equations, so multi regression analysis was used for the development of models.

Multiple regression analysis method was used to determine the relation between multiple independent variables (input) and single dependent variable (output). Mathematical equations were developed using statistical software, namely Statistical Package for the Social Sciences (SPSS). In order to assess the influence of input parameters on output, stepwise regression was used. Assessment of SPSS software based predicted values were evaluated by statistical parameters like coefficient of determination (R^2), ANOVA, parameters coefficients and Variable Influencing Factor (VIF). The parameters chosen were found to be statistically more significant. The predicted values from multiple regression method and field measured values were compared. The R^2 value for emission model is 0.82 and for concentration model it is 0.81, for 95% level of confidence, which shows very good correlation.

A comparison was made between Multiple Regression Analysis Model and ANN model results. ‘Trainlm’ algorithm revealed that, MRA model gave better performance than ANN with lower RMSE and high MAPE values and higher prediction accuracy (VAF) value for all the predicted variables. The VAF values obtained for MRA is 87.1 per cent, RMSE is 3.22 and MAPE is 33.7 per cent. Finally, to validate developed models, field measured values were compared with SPSS model predicted values and USEPA predicted values. Analysis revealed that USEPA was giving around 99 per cent error and SPSS model was giving error of within 20 per cent. Therefore, SPSS models developed as part of this research work may be used for dust prediction from drilling activity under Indian Geo-Mining and weather conditions.

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ACRONYMS

AAQ	Ambient Air Quality
AAPD	Average Absolute Per cent Deviation
ABL	Atmospheric Boundary Layer
ACGIH	American Conference of Government Industrial Hygienists
AERMOD	American Meteorological Society/Environmental Protection Agency Regulatory
ANN	Artificial Neural Networks
ANOVA	Analysis of Variance
BOP	Bhuvaneshwari Opencast Project
CA	Cluster Analysis
CFD	Computational Fluid Dynamic
CPCB	Central Pollution Control Board
CWP	Coal Worker's Pneumoconiosis
CIL	Coal India Limited
DCP	Dynamic Component Program
FDM	Fugitive Dust Model
FFT	Fast Fourier Transformer
GFA	Glass Microfiber Filter
GLC	Ground Level Concentration
HEMM	Heavy Earth Moving Machinery
IPM	Inhalable Particulate Mass
ISC3	Industrial Source Complex Terrian-3
ISCST3	Industrial Source Complex Short Term Model-3
ISRM	International Society for Rock Mechanics
LPM	Litter Per Minute
MAPE	Mean Absolute Percentage Error
MSE	Mean Square Error
MCL	Mahanadi Coalfields Limited
MRA	Multiple Regression Analysis
NLC	Neyveli Lignite Corporation
NIOSH	National Institute for Occupational Safety and Health Model
NAAQS	National Ambient Air Quality Standards

ACRONYMS

NSSGA	National Stone, Sand and Gravel Association
PCA	Principal Component Analysis
PSI	Protodyakonov’s Strength Index
PTFE	Polytetra flurothylene
PPM	Parts Per Million
PPC	Parts per cubic centimeter
PM	Particulate Matter
PKOC-II	Prakasam Khani Opencast-II Project
RPM	Respirable Particulate Mass
RBF	Radial Basis Function
RMSE	Root Mean Square Error
RSPM	Respirable Suspended Particulate Matter
SCCL	The Singareni Collieries Company Limited
SME	Site Mixed Emulsion
SOP	Samaleswari Opencast Project
SPSS	Statistical Package for Social Sciences
SPM	Suspended Particulate Matter
TSP	Total Suspended Particulate
TSP	Total Suspended Particulate
USEPA	United States of Environmental Protection Agency
VIF	Variable Influence Factor

CHAPTER - 1

INTRODUCTION

This chapter primarily deals with various sources of dust production in mines, classification of dust, effects of dust pollution. It also highlights the necessity to take up the research in the chosen area, along with research problem statement and objectives.

In order to keep up with the increasing demand for coal and other minerals, large opencast projects are being planned and executed. Accordingly, Heavy Earth Moving Machinery (HEMM) with higher capacity are introduced to increase the rate of production, which in turn has triggered more and more dust pollution also. Dust is a generic term that can be used to define fine particle that is suspended in the atmosphere. Dust generation not only comes from mining activity, but also from various other sources such as soil, sea salt, fossil fuel combustion, burning of biomass and industrial activities etc. The size of dust particle ranges from a few nanometers to micrometers. Some of the reasons to dust dispersion are turbulent action of air, high temperature and surface roughness.

Dust can be generally classified into nuisance dust, inhalable dust and respirable dust. Nuisance dust comprises of particles with diameter ranging from 50µm to 1mm. Generally, this type of dust can be called as Total Suspended Particulate matter (TSP), whereas, the size of inhalable dust particles and respirable dust are less than 10µm and 2.5µm respectively, and the latter settles in the alveoli of human lungs. All these may have health implications on human beings, particularly on mine workers who are constantly exposed to these types of dust (Anon, 1998). Dust produced from different activities in a mine may disperse to far distances and may cause unwanted effects such as dust pollution, loss of visibility on roads, loss of vegetation. So, it is necessary to predict the dust concentration at different distances for various sources of dust generation.

Coal, being one of the primary sources of energy and due to the fact that it is inexpensive compared to other fossil fuels, the rising demand for energy has been met mostly through coal. To meet this ever increasing demand for coal and other natural resources, the rate of extraction is being increased and accordingly the quantity of dust produced has also gone up. Generation of dust produced from surface mines is much more compared to underground mines and causes a myriad of pollution problems to the environment. The primary sources of dust generation in surface mines are drilling, blasting, loading, haul road, overburden dump yard, coal dump yard, coal handling plant, etc.

In surface mining operations, the sources of dust are categorized into three types: point sources, line sources and area sources. Various point sources are drilling, loading and unloading. Similarly, line sources are haul roads, unpaved roads, etc. In the last category, i.e. area sources are coal handling yard, dump yard, etc.

Among all other activities, drilling is one of the sources for dust generation which requires special attention. Dust emanating from different sources especially from drilling consists of particles with varying sizes. Particulate Matter (PM) is one of the major pollutants in mining activities. It consists of PM2.5, PM10 and TSP, among which PM2.5 and PM10 are more harmful to human health, which cause lung diseases. Dust produced from drilling operation is dependent on various factors such as drill diameter, drill speed, thrust, type of drill bit, rock properties, etc.

The dust produced from drilling operation is typically in fugitive form because of mechanical action such as drill bit rotation and speed of drill bit which comprises of a combination of reducing particle size as well as it follows ejection of dust into atmosphere. Amount of energy imparted to material and duration (frequency) of the activity can accelerate the dust production process (Thompson and Visser, 2007). Dust can be dispersed even upto 500m away from the source and further dispersion of dust becomes lesser (Trivedi et al., 2009).

Ambient air pollution becomes higher in the surrounding areas of mine as well as in the work places. Workers on site are frequently exposed to fugitive dust, which is more harmful to human health. Respirable concentration and benzene soluble matter in Suspended Particulate Matter (SPM) are also serious threats to human health. Concentration level of Total Suspended Particulate matter (TSP) and PM10 were found to be more in the working zone (Ghose and Majee, 2007). Dust emission from various activities not only affects the environment, but also gets deposited on clean surfaces such as shovels, dumpers and buildings. Dust emission has always been a problem for the local residents.

Effects of dust on agriculture and ecology of an area are determined by concentration of dust particles in the ambient air, their size distribution, deposition rate and chemical properties. These factors can influence the chemistry of soil and health of surrounding plants, meteorological and local microclimate conditions, as well as penetration rate of dust into vegetation. Apart from vegetation, dust deposition can affect animal communities and woodlands (Balkau, 1993).

Determination of dust concentration is necessary in surface mining areas, which will be helpful in maintaining green belt sensitive areas, where the concentration of air pollutants exceed standard limits (Chakraborty et al., 2001). Before executing the projects, it is necessary to predict dust concentration using suitable prediction models to assess the impact of dust on environment and also for regulatory purposes.

Different uses of dust dispersion models are (Moussiopoulos et al., 1996):

- Regulatory purposes, i.e., to assess compliance with air quality standards and guidelines.
- Designing air quality management systems.
- Deciding where to locate new pollution sources to minimize pollution impact.

- Describing the sequence of processes, i.e., hourly average of SO_2 concentrations from power station.
- Explanation of buffer zones.

Some of the widely used dust prediction models are Fugitive Dust Model (FDM) and Industrial Source Complex Terrian-3 (ISC3) model, developed by US Environmental Protection Agency (USEPA). However, these models are not able to predict the dust concentration in mines accurately (Cole and Zapert, 1995).

1.1 Permissible Levels of Dust

The American Conference of Government Industrial Hygienists (ACGIH) has given standards for various sizes of dust particles and also the United States of Environmental Protection Agency (USEPA) has made standards for dust categories. Some of the standards are given in Tables 1.1 and 1.2, which are taken as aerodynamic diameter of particulate matter (Anon, 2002).

Many studies were carried out on PM10 particles and it was reported that PM10 particles caused lung related diseases in humans. If dust quantity is more than $50\mu g/m^3$ in 24hour average concentration, it is more significant in increasing death rates (Anon, 1996).

Table - 1.1 ACGIH standards for various dust and their percentages (Anon, 1991)

Respirable Dust		Inhalable Dust	
Particle Aerodynamic Diameter (µm)	**Respirable Particulate Mass (RPM) %**	**Particle Aerodynamic Diameter (µm)**	**Inhalable Particulate Mass (IPM) %**
0.0	100.0	00.0	100
1.0	097.0	01.0	97.0
2.0	091.0	02.0	94.0
3.0	074.0	05.0	87.0
4.0	050.0	10.0	77.0
5.0	030.0	20.0	65.0
6.0	017.0	30.0	58.0
7.0	009.0	40.0	54.5
8.0	005.0	50.0	52.5
9.0	001.0	100	50.0

Table - 1.2 Respirable dust standards as applied to the mining industry by the U. S. department of labor

Particle Aerodynamic Diameter (µm)	EPA's PM10 Particulate Mass (%)
2.0	90.0
2.5	75.0
3.5	50.0
5.0	25.0

Prediction of dust concentration level is necessary for various activities in opencast mines, in order to maintain the pollution levels within permissible limits. The Central Pollution Control Board (CPCB) has given permissible levels of dust concentration in ambient air at coal mine areas in India are given in Table 1.3.

Table - 1.3 National Ambient Air Quality Standards (NAAQS) for coal mines (CPCB-2009)

Pollutants	Time Weighted Average	Concentration in Ambient Air		
		New Coal Mines (Commenced after 25.09.2000)	**Existing Coal Mines (Commenced prior to 25.09.2000)**	**Method of Measurement**
Particulate Matter (size less than 10 ⇑g) or PM$_{10}$⇑g/m^3	Annual	180 µg/m^3	215 µg/m^3	Gravimetric, Beta attenuation
	24 hours	250 µg/m^3	300 µg/m^3	
Particulate Matter (size less than 2.5 ⇑g) or PM$_{2.5}$⇑g/m^3	Annual	40⇑g/m^3	40⇑g/m^3	Gravimetric, Beta attenuation

1.2 Effects of Dust Pollution

Dust pollution causes various problems within and outside the mines. Dust emanates from different activities directly affects the people working in the mines, dust deposition on HEMM and other machinery can damage them. Thick dust cloud can reduce the visibility on haul roads, which leads to accidents. As the dust can disperse for long distances, it may deposit on the surrounding areas and can lead to loss of vegetation and affects the heath of surrounding human habitats. Among all types of dust particles, PM10 is more hazardous to human respiratory system. The human respiratory system is classified in to three regions as shown in Figure 1.1, the first one being extra thoracic region which consists of nose, mouth, pharynx and larynx, the trachea bronchial region, which extends from the trachea to the terminal bronchioles and finally the alveolar region, which contains the lungs (Hinds, 1999). The alveolar region consists of some scavenging cells called as microphages, which combine with fine particles and digest them. Dust particles of minerals are insoluble and are untreated by microphages. Silica and coal dust will interfere with functioning of microphages and hence will not be able to remove these particles successfully, and instead it causes scarring in the lung tissue, also known as fibrosis (Wagner, 1980).

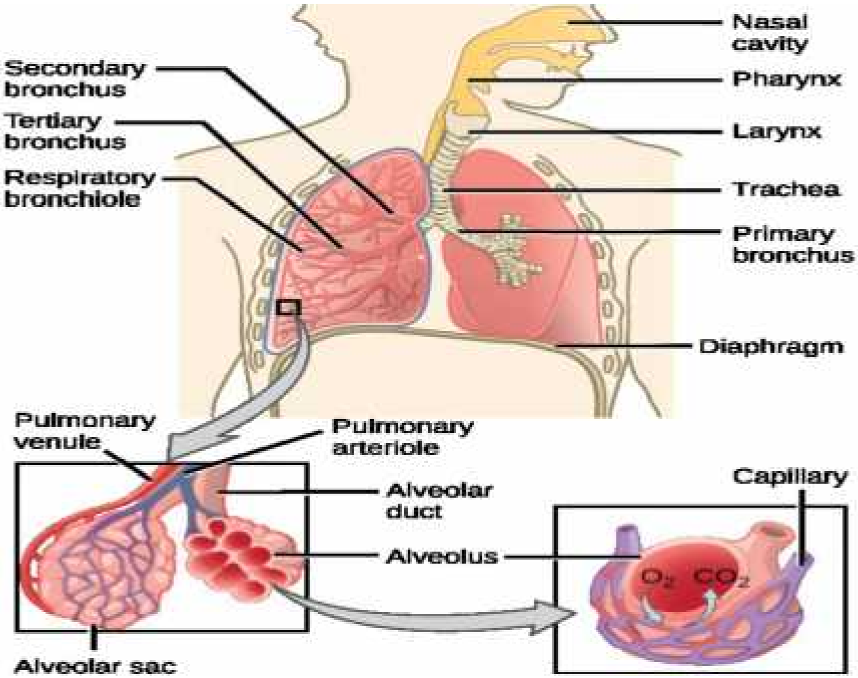

Fig. 1.1 Human respiratory system (Anon, 2015)

Coal Worker's Pneumoconiosis (CWP) and Silicosis are lung diseases that adversely affect the health of mine workers. Depending on the severity of the lung disease, symptoms range from reduced breathing capacity to death.

Some important parameters that influence pneumoconiosis are dust concentration, particle size and duration of exposure. One of the reasons for pneumoconiosis is mass concentration in the form of respirable size. The dust concentration is determined in three ways such as micrograms per meter cube ($\mu g/m^3$), parts per cubic centimeter (PPC) and surface area of particles per unit volume. The next important parameter for pneumoconiosis is the size of particles. Smaller particles pass through the upper respiratory system of human body and settle down on lungs and cause pneumoconiosis. The health problems caused due to dust can be due to short term exposures or long term exposures. Asthma attacks, acute bronchitis and increased susceptibility to respiratory infections are some of the common effects found in workers who are exposed to dust for a short duration. Some of the typical effects of long term exposure are reduced lung functioning, development of chronic bronchitis, increased respiratory symptoms, such as irritation of airways, coughing or difficulty in breathing. Pneumoconiosis is characterized by the formation of fibrous tissues in lungs due to dust deposition (EPA 2003, and Anon 1995).

1.3 Research Problem Statement and Objectives of the Study

Extraction of coal / ore from surface mining consists of Drilling, Blasting, Loading, Transportation, Dumping, Crushing operations etc. Dust is produced at every stage during these operations. Among them, drilling operation is one of the primary steps in production process. Generation of dust by drilling operation usually is in fugitive form and consists of various particulate matters, which are more dangerous than other types of dust particles to human health. The prediction of dust from drilling operation using USEPA model, i.e. ISC3, is over predicting the dust concentration levels in the atmosphere and this USEPA model is not suitable for Indian Geo-environmental conditions (Reed et al., 2002). The ISC3 model may not predict the dust concentration resulting from mining operations accurately, since ISC3 model is designed for predicting dust dispersion from stationary sources (Cole and Zapert, 1995, Reed, 2005).

The primary aim of this research work is to develop a mathematical model to predict the concentration of dust produced due to drilling operation in surface mines under Indian Geo-environmental and Mining conditions.

Various input parameters for the development of model are drilling operational parameters, rock properties and meteorological parameters.

- Drilling operation parameters:

  - Drill diameters
    - Coal mines – 150mm and 250mm
    - Limestone mines – 32mm and 115mm
    - Granite quarries – 34mm, 38mm and 115mm
  - Penetration rate (m/min)
- Rock properties:
  - Density (g/cc)
  - Moisture content (%)
  - Rebound hardness number
  - Compressive strength (MPa)
- Weather conditions:
  - Temperature (^{o}C)
  - Humidity (%)
  - Wind speed (m/s)

1.3.1 Objectives of the study

The objectives of present research work are as follows:

To monitor the dust produced by drilling operation in different types of rock formations such as sandstone, coal, limestone and granite.

- To identify the most influencing parameters responsible for the generation of dust during drilling in surface mines using regression analysis.
- To develop a mathematical model using multiple regression analysis and artificial neural networks, and to compare and validate the developed models.
- Simulations of dust dispersions from drilling operation in surface mines.
- To develop a software to predict dust concentration levels due to drilling operation under given geo-mining and environmental conditions.

1.4 Structure of the Thesis

The research work consists of literature review, carrying out field investigations in different rock formations, development of dust prediction models, simulation and validation of the models. This thesis is organized as following chapters.

Chapter 1: Introduction

Introduction chapter details about various sources of dust generation, classification of dust, effects of dust pollution, permissible levels of dust concentration and also gives an outline of the background to the research problem along with objectives.

Chapter 2: Literature Review

This chapter presents review of relevant literature on the dust dispersion phenomenon in surface mines, causes and effects of dust, factors influencing dust emission and dispersion, various dust dispersion models (Industrial source complex short term model, AERMOD model, Fugitive dust model, Box model algorithm, Gaussian model). Information was also given about some important works of previous researchers. Basics of Artificial Neural Networks (ANN) and Multiple Regression Analysis (MRA) are also discussed.

Chapter 3: Field Investigations

This chapter gives details about dust monitoring equipment, methodology adopted for dust monitoring, determination of required rock properties and field investigations carried out in eight surface mines.

Chapter 4: Results and Analysis

This chapter gives details about development of dust prediction models using ANN and MRA methods based on field data, simulation of dust dispersion using ANSYS software, analysis of the influence of different parameters on dust emission rate and validation of developed models.

Chapter 5: Conclusions and Recommendations

The summary of conclusions drawn from the research work carried out and also further recommendations addressing various issues for the future work are described in this chapter.

CHAPTER - 2

REVIEW OF LITERATURE

Dust is generated from almost all activities involved in the process of removal of overburden and ore from opencast mines. Dust emanating from different sources disperses to longer distances and then deposits at a place. Phenomena of emission and dispersion of dust depends upon many parameters such as operational parameters, rock properties, meteorological parameters, etc. This chapter deals with literature review pertinent to the subject area such as sources of dust generation, causes and effects of dust, factors influencing dust generation and dispersion along with different dust dispersion models.

Quantitative assessment of PM10 is essential for determining the actual zone of influence for dust in mining activities. Therefore, monitoring stations have to be systematically located in the areas to get time averaged dust concentration at the site. However, these dust concentrations are resultant of the airborne dust and the dust generated due to mining activities. The accuracy with which one can estimate these concentrations determines the efficiency of the preventive measures incorporated within the environmental management plan. Further, this information can help in convincing the people living nearby about the exact impact of mining related air pollution due to PM10.

2.1 Sources of Dust in Mining

Significant amount of dust is generated due to various operations in opencast mines such as drilling, blasting, loading, transportation, OB dumping, etc., (Chaulya, 2004; Ghose and Majee, 2000). Ghose and Majee, (2007), and Trivedi et al. (2009), concluded that PM10 will be one third to half of total particulates produced from different activities.

For the removal of any deposit from insitu using surface mining, initially top soil will be removed followed by waste rock and ore using drilling and blasting operations. Subsequently, the material is loaded and transported to dump yard or crushing plant. Dust generated from the drilling operation usually is in fugitive form and it will disperse into the environment in a defined flow stream (Pandey, 2012).

Nair et al. (1999) reported that per meter drilling of a 250mm diameter drill hole in an iron ore opencast mine produced 1.46kg of Respirable Suspended Particulate Matter (RSPM) into the atmosphere. They also reported that though the drilling was the shortest duration mining operation, it produces maximum quantity of RSPM.

2.2 Causes and Effects of Dust

Different particle size of dust produced by various activities in the mine gets dispersed into atmosphere. Particles of more than 10µm size can be easily arrested during inhalation process, whereas PM10 can settle down on the respiratory system, but PM2.5 can easily join with blood through alveolus in lung system. Exposure to such an environment may cause lung and heart diseases. Larger particles may affect nose, throat and cause irritation to eyes (Anon, 1995).

Ghose and Majee (2007) stated that due to opencast coal mining, ambient air pollution is more in neighboring areas and also more pollution in work zones. Workers who work near to the operation are getting more fugitive dust, which is harmful to human health. Respairable fractionation concentration and benzene soluble matter in Suspended Particular Matters (SPM) are more dangerous to human health. American Conference of Governmental Industrial Hygienists (AGGIH) has concluded that if coal dust is more than 5 percent, it is similar to quartz dust (Anon, 1991).

Uranium mines produce considerable amount of particulate matters and are more dangerous to human health compared to other types of mine dust. Dust generated from uranium mines contains heavy metals such as manganese, vanadium and arsenic, and these are radionuclides causing more harm to human health (Fernandes et al., 1995).

NIOSH (1995) stated that Federal Coal Mine Health and Safety Act of 1969 derived limits of 2.0mg/m^3 for respairable dust in opencast coal mining operations. In atmosphere, if silica content exceeds 5%, repairable dust is determined by using Equation (1). Similarly, various countries have proposed various permissible dust limits (Table 2.1).

$$Ø = \frac{10}{\%\ \text{Silica}} \qquad \text{--------- Equation (1)}$$

where,

Ø = Respirable dust limit (mg/m^3)
Silica = % silica in dust as fraction

Table - 2.1 Permissible dust limits in various countries
(United States National Institute for Occupational Safety and Health, 1995)

County	Recommended Values (mg/m^3)	Comments
Australia	3.00	Coal dust with : 5% respirable free silica
Italy	3.33	Coal dust with ~ 1 % quartz
Germany	0.15	Quartz (including cristobalite and tridymite)
France	05 (alveolar) 10 (inhalable dust)	Coal dust without silica
United Kingdom	3.80	Coal mine dust
United States	2.00	Coal dust with ~ 5% silica

Inhalation of dust can causes myriad of respiratory and lung diseases some of which are described here.

2.2.1 Pneumoconiosis

Pneumoconiosis is a group of interstitial lung diseases caused by inhalation of certain dust particles and lung tissues reaction to the dust. Some types of pneumoconiosis are asbestosis, silicosis and coal workers pneumoconiosis (Pandey, 2012). These are caused due to inhalation of asbestos fibers, silica dust and coal mine dust, respectively. Development of these three diseases may take several years, and till then it may not be possible to realize or to discover the disease. Among these diseases, silicosis develops rapidly and can occur in short duration. This disease often leads to lung impairment, disability and premature death (Hathaway et al., 1991). In the U.S., annually more than 250 human deaths are being caused by crystalline silica (Anon, 1997).

2.2.2 Silicosis

Silicosis is a fibrotic lung disease that is caused by over exposure to dust composed of free crystalline silica. It is irreversible, progressive, incurable, and at later stages leads to disabling and eventually fatality. The silicosis risk depends on amount of free crystalline silica inhaled and actually deposited in the alveolar region.

There are three levels of silicosis: chronic silicosis, which occurs after ten years of exposure; accelerated silicosis, which occurs between 5-10 years of exposure; and acute silicosis which occurs within a few weeks to five years of exposure to silica (Anon, 1996). Silicosis has no cure and is generally fatal. Miners are prone to silicosis, both when working in underground and the surface.

2.2.3 Byssinosis

Byssinosis is an obstructive lung disease, usually characterized in the initial stages by shortness of breath, chest tightness and wheezing on the first day after returning to work, but with symptoms increasing and becoming more permanent as the disease progresses.

2.3 Factors Influencing Dust Emission and Dispersion

Meteorological parameters (wind velocity, humidity, temperature and dispersion co-efficient) are required for simulating the dust dispersion from surface mines. Generally, in daily routine the atmospheric condition is not stable, it may be varying at any time (Tyson and Prestone, 2000). As downward drag force of dust particles is lesser compared to wind force, dust may be dispersing to far of distances and settles down during calm condition of atmosphere. Dust particles in atmosphere may settle down at shorter distances (Anon, 1998). Piccot et al., (1996) stated that the atmospheric stability classes are more significantly affect the emission rate. Initially, the dust eminates from drill holes, later it may disperse to long distances based on various factors. This dispersion phenomena was characterized as dispersion coefficients, which were derived by Giffered Pasquils in his formulae (Peavy et al., 1985, Surendra Roy et al., 2010).

In general, dust dispersion happens towards air flow direction. Wind speed plays an important role in transporting the pollutants. At higher velocity, the denser particles settle down in their respective places, but lighter particles move in wind direction (Chaulya, 2004). Dispersion of dust upto 500m from coal mine is more, and further dispersion of dust becomes less (Trivedi et.al., 2009).

Estimation of emission from respective source is an important factor for any kind of dispersion models. Initially dust emitting from source is mainly dependent on various factors such as moisture content, rock density, hardness of material and compressive strength of rock, etc. Moisture content present in rocks virtually leads to less particulate emission (Cole and Kerch, 1990). Bhandari et al. (2004) have concluded that low density rocks produce more fines than high density rocks.

2.4 Dust Prediction Models

It is necessary to predict dust generated from various mining activities using suitable prediction models. Dust dispersion models are predictive tools used to simulate atmospheic transports and diffuse contaminants from industrial sources of pollution. Many researchers are now focusing on regional dispersion models for specific activities. A few models were developed for industry purposes. Furthermore, some of the past research has focused on dust dispersion modelling in mining industry. Some commonly used models are Industrial Source Complex Short Term Model (ISCST3), American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD), Fugitive Dust Model (FDM), Box Model Algorithm and Gaussian Model Algorithm. These models are developed by U.S. Environmental Protection Agency (USEPA). However, these models are not able to predict dust concentration in the atmosphere as close as to the real field values in mining industry (Cole and Zapert, 1995).

2.4.1 Industrial source complex short term model (ISCST3)

The ISCST3 Model is a steady-state Gaussian plume model which can be used to assess pollutant concentration from a wide variety of sources associated with an industrial source complex. The ISCST3 model estimates concentration or deposition value for each source and receptor combination for every hour of input meteorology and calculates user selected short-term averages. The input data for model are user source dimensions such as emission rate, wind speed, wind direction, ambient air temperature, mixing height, stability class, and receptor coordinates (Anon, 1995). The following equation gives dust concentration.

$$X = \frac{QKVD}{2\pi u_s \sigma_y \sigma_z} \exp\left[-0.5 \left(\frac{y}{\sigma_y} \right)^2 \right]$$ …………Equation (2)

where,

X = Concentration (µg/m^3)

Q = Pollutant emission rate (g/s)

K = 1000000 default value

D = Decay term (dimensionless)

V = Vertical term

σ_Y&σ_Z = Standard deviation of lateral & vertical concentration distribution

u_s = Mean wind speed (m/s)

y = Crosswind distance from source to receptor (m)

The Pasquill and Gifford formula is basically used for finding out emission rate for any activity (Chaulya et al., 2003).

$$C = \frac{Q}{\Pi u \sigma y \sigma z}$$ ……………Equation (3)

where,

C = Difference in pollutant concentration (µg/m^3)

Q = Pollutant emission rate (g/s)

Π = 3.14159

U = Mean wind speed (m/s)

σ_y = Standard deviation of horizontal plume concentration evaluated in terms of downwind distance

σ_z = Standard deviation of vertical plume concentration evaluated in terms of downwind distance

Palanivelraja et al. (2008) evaluated USEPA-ISCST3 model for prediction of short term SO_2 concentration in the ambient environment of Neyveli Lignite Corporation (NLC) Complex. Reliability of ISCST3 dispersion model was verified using short term air quality and micro meteorological data from the study of Chochalingam (1988) pertaining to Neyveli Lignite Corporation Environment. The model ISCST3 was applied in two different approaches as ISC modelling, option 1 and option 2. Both options of the ISCST3 model run successfully for predicting SO_2 concentrations. Simulations were carried out for three sets of eight hourly meteorological data, which included various combinations of stability and wind speed. Collective frequency distributions of observed and predicted SO_2 concentrations for both modelling options and all sampling stations have been drawn and compared. It is understood from the results that ISCST3 model over predicted the eight hour average SO_2 concentrations. In order to overcome the over prediction, a correction factor was developed by them.

Cole and Zapert (1995) studied the ISC3 model to test three Georgia stone quarries. It was stated that ISC3 model was over predicting particulate concentrations based on data obtained by the U.S. Department of Energy's Hanford, WA, site. In their investigation, emission rates for operations were determined. Also, they modelled dispersion of emitted particulates. Further, modelled versus measured particulate concentrations were compared in each of the three stone quarries. In general, number and type of PM10 sampling stations were unknown. However, it was determined that at least two sampling stations at each site were available. There was a primary downwind site and a site located upwind for prevailing winds to allow the subtraction of ambient PM10 concentrations. The study concluded that there could be two reasons for over prediction, the ISC3 model failed at that time to account for any deposition of the particulates and the other reason was that the emissions factor for unpaved roads over predicts the amount of emissions from haul trucks. Emissions factor was cited as primary possible cause for over prediction because, during the study it was noticed that the hauling operations contributed

79% – 96% of the PM10 emissions from the entire quarrying operation (Cole and Zapert, 1995). They used an initial deposition routine created by EPA and found that it reduced the modelled results by 5%. However, even with this reduction in modelled PM10 concentrations, there was an over prediction. This has led the National Stone, Sand and Gravel Association (NSSGA) to embark on a series of studies published during 1991–2001, that attempts to better quantify the PM10 emissions from haul trucks (Richards and Brozell, 2001).

Reed (2004) developed a computer based model named as Dynamic Component Program (DCP), related to dust dispersion from haul trucks. To develop the model, field investigations were carried out in two mines. Finally to validate the developed model, predicted values were compared with field measured values and predicted values from ISC3 model. Results indicated that DCP model predicted values of average an 85% improvement over ISC3 dust dispersion model results. DCP model predicts PM10 more accurately, when the frequency of haul trucks is more than 200 trucks/day.

2.4.2 AERMOD Model

American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) was one of the tools available for dust dispersion modelling in mining industry. AERMOD was developed to replace the Industrial Source Complex Model-Short Term (ISCST3) as USEPA preferred model for many small scale regulatory applications. In this model, the boundary layer is characterized with computation of length, surface friction velocity, surface roughness length, sensible heat flux, convective scaling velocity, etc. These parameters were used in conjunction with meteorological measurements to characterize vertical structure of the wind, temperature and turbulence (Cimorelli et al., 2004).

The general equation form of AERMOD dispersion model with terrain is as follows:

$Ct \{ Xr, Yr, Zr \} = f\ Ccs\{ Xr, Yr, Zr \} + (1-f)\ Ccs \{ Xr, Yr, Zp \}$-------------- Equation (4)

where,

$Ct \{Xr, Yr, Zr \}$ = Total concentration ($\mu g/m^3$)
$Cc,s \{ Xr, Yr , Zr \}$ = Concentration from horizontal plume ($\mu g/m^3$)
$Cc,s \{ Xr, Yr , Zp \}$ = Concentration from the terrain following plume ($\mu g/m^3$)
$\{Xr, Yr, Zr\}$ = Receptor coordinates (m)
Zp = Receptor height above local ground (m)
Zt = Local terrain height (m)
f = Weighting factor

Huertas et al. (2012) studied the performance of two dust dispersion models such as ISC3 and AERMOD. To validate these models, predicted values were compared with field monitored values. Correlation between predicted AERMOD values and measured values was 0.857 and similarly, between predicted ISC3 and measured values it was 0.705, indicating that AERMOD model has higher correlation with field measured values.

2.4.3 Fugitive dust model (FDM)

Fugitive Dust Model (FDM) is a programmed air quality model particularly designed for computing concentration and deposition impacts from dust sources. Sources may be point, line or area sources. This model generally works based on Gaussian Plume formulation of determining concentrations. Initially user has to describe the emission rate for each source and their respective particle size classes. FDM itself calculates gravitational settling velocity and a deposition velocity of dust particles for each class.

Further, required concentration and deposition is determined with respect to receptor locations (Anon, 1991).

Abdul-Wahab et al. (2005) carried out performance evaluation of FDM model to assess the impact of fugitive dust emission from a cement plant in Oman. TSP concentrations were determined at representative points located at the nearest to Plant site, i.e. at three existing residential houses. Furthermore, dust impact arising from cement plant on three existing residential houses was predicted by FDM model. Emission rates of dust from various activities of cement plant were estimated by using emission factors technique, which engaged in cement manufacturing activities. To validate FDM model, predicted and measured values were compared and the correlation coefficient was 0.89.

Trivedi et al. (2009) identified different sources of dust generation and quantified dust emission rates for different point, area and line sources, based on research studies carried out in one of the opencast coal projects of Western Coalfields Limited, India. Studies were carried out in winter season and five ambient air quality stations were selected to measure Respiratory Particulate Matter (RPM) and Total Suspended Particulate Matter (TSPM). Initially, emission values were calculated using Modified Pasquill and Gifford formula for ground level emissions and FDM model was used for prediction. Results revealed that predicted values by FDM Model were 68 – 92% of observed values. Variation between observed values and predicted values of TSPM may be due to non-accountability of emissions from sources other than mining activities, domestic use of fuels, transportation nearby power plant, cement plant, etc. Results also showed that dispersion modelling using FDM indicates that dust generated due to mining activities does not contribute to ambient air quality in surrounding areas beyond 500m in normal meteorological conditions.

Singh et al. (2006) have carried out studies on the performance evaluation of FDM and ISC3 models for a gold mine. Input chosen for these models are: emission rate and meteorological parameters. Results revealed that FDM model gives more accurate results than ISC3 model.

2.4.4 Box model algorithm

Box model is one of the simplest modelling algorithms. It assumes that the air shed is in the form of a box assuming to be a homogeneous concentration. Box model is represented using the following equation:

$$\frac{dCV}{dt} = Q*A + u*C_{in}*W*H - u*C*W*H \quad \text{..............Equation (5)}$$

where,

Q = Pollutant emission rate per unit area (g/m^2)

C = Homogeneous species concentration within the air shed (µg/s)

V = Volume described by box (m^3)

C_{in} = Species concentration entering the air shed (µg/s)

A = Horizontal area of the box (m^2)

L = Length the box (m)

W = Width of the box (m)

U = Wind speed (m/s)

H = Mixing height (m)

This mathematical model is very limited in its ability to predict dispersion of pollutant over an air shed because of its inability to use spatial information (Collet and Oduyemi, 1997).

2.4.5 Gaussian model algorithm

The most common mathematical models used for air dispersion is Gaussian model. Following is the Gaussian equation generally used for point source emissions:

$$X = \frac{Q}{2\pi u_s \sigma_x \sigma_z}\left[exp\left\{-0.5\left(\frac{y}{\sigma_y}\right)^2\right\}\right]\left[exp\left\{-0.5\left(\frac{H}{\sigma_z}\right)^2\right\}\right] \ldots\ldots\ldots\ldots\text{Equation (6)}$$

where,

X = Concentration ($\mu g/m^3$)

Q = Pollutant emission rate (g/s)

H = Source height

σ_Y&σ_Z = Standard deviation of lateral & vertical concentration distribution

u_s = Mean wind speed (m/s)

y = Crosswind distance from source to receptor (m)

Chaulya et al. (2002) carried out studies on development of dust emission models for different mining activities. Assessment of air quality and prediction of dust emission from different activities are necessary to prevent and minimize the dust particles emitting into environment. Field investigations were carried out in seven opencast coal mines, for the development of models. To validate newly developed models, predicted values were compared with field measured values and also with FDM predicted values. Results revealed that correlation coefficient of measured and predicted values were ranging from 85.6 to 99.9. Final models developed for different mining activities are given in Table 2.2.

Table - 2.2 Empirical formulae used for emission rate (Chaulya et al., 2002)

Activity	Empirical Equation
Drilling	$E=0.0325[[(100-m)su]/[100-s)m)]^{0.1}\ (df_d)^{0.3}$
Overburden point loading	$E= [0.018\ ((100-m)/m)^{1.4}\ (s/100-s)))(uhfl)^{0.4}]$
Coal loading	$E = [(100-m)/m)^{0.1}\ m(m/(100-s))^{0.3}h^{0.2}(u/0.2+1.05u))(fl(15.4+0.87fl))]$
Haul road	$E= [((100-m)/m)^{0.8}(s/(100-s))^{0.1}u^{0.3}(2663+0.1(v+fc))10^{-6}]$
Overburden unloading	$E= [1.76\sqrt{}h+((100-m)/m)^{0.2}(s/(100-s))^{2}u^{0.8}(cf)^{0.1}]$
Coal handling plant	$E= [((100-m)/m)^{0.4}(a^{2}s/(100-s))^{0.3})(u/160+3.7u))]$
Overall mine	$E=u^{0.4}a^{0.2}(9.7+0.01c+b/(4+0.3b))]$

where,

E = Emission (g/s)

m = Moisture content (%)

s = Silt content (%)

u = Wind speed (m/s)

d = Hole diameter (m)

f_d = Frequency of drilling

h = Drop height (m)

l = Size of loader (m^3)

f = Frequency of loading (No. /h)

a = Area (m^2)

b = OB handling

c = Coal production

Gillies et al. (2005) have carried out some studies on dust emission from unpaved road of variety of wheeled vehicles at Ft. Bliss, Texas, USA. They concluded that there are only two variables which influence production of PM10 dust particles such as vehicle weight and vehicle speed. Empirical relation was proposed to determine Emission (E) for PM10, as follows:

$$E = 0.003.\ W.S \qquad \text{-----------------Equation (7)}$$

where,

W = Vehicle weight (kg)

S = Mean vehicle speed (km/h)

2.5 Artificial Neural Networks

A neural network is a statistical modeling technique, which simulates some aspects of human learning process. Human can learn by examples using trial and error method and learn to recognize respond to patterns. Neural networks can be designed to operate in a somewhat analogous manner. They can be trained in a defined pattern in data and in the process to create a mapping of input to output variables in an underlying process. Using same mapping logic, subsequently predictions can be made for other input data. In addition to this, ANNs are able to deal with incomplete information or noisy data and are very effective especially in situations where it is not possible to define the rules or steps that lead to the solution of a problem. ANN provides linear and nonlinear modeling without the requirement of preliminary information and assumption as to the relationship between input and output variables. This provides ANN an advantage over other statistical and conventional prediction methods such as logistic regression and numerical methods, in which nonlinear interactions among variables must be modeled in explicit functional form. Neural networks may be used as a direct substitute for auto correlation, linear regression, trigonometric, multivariable regression and other statistical analysis / techniques. Some of the terminologies used in ANN are developed based on human biological model of brain. A neural network consists of a set of connection neurons. The input neurons receive input signals from input variables and perform some kind of transformation of input and transmit output to other neurons. This neural network consists layers of neurons connected, so that input layer receives input signals from the preceding layer of neurons and pass the output onto the subsequent layer. The most important characteristic of ANN is adaptive in nature, where initially the network learning is by some examples and subsequently replaces programming. These features make such computational models very attractive in application domains.

A neuron is a real function of the input vector (y_j…..y_k). The output is obtained as:

$$f(x) = fa_i + \sum_{n}^{k} W_{ij} \times Y_j \quad \text{..............Equation (8)}$$

where 'f' is a function, typically the sigmoid (logistic or tangent hyperbolic) function.

A graphical presentation of neuron is given Fig. 2.1. Mathematically, a Multi-Layer Preceptor network is a function consisting of compositions of adjustable weighted (w) sums of the functions corresponding to the neurons.

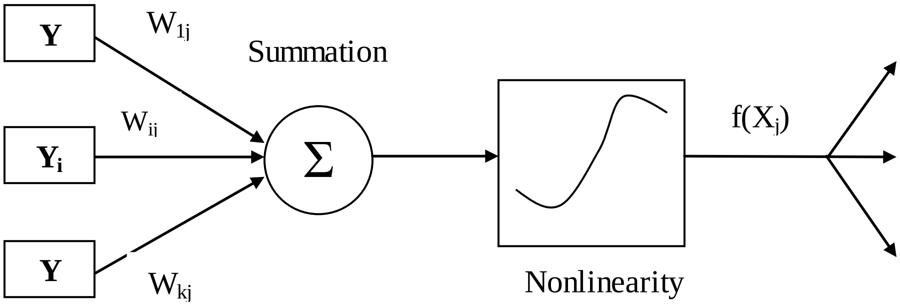

Fig. 2.1 Structure of neurons

2.5.1 Back-propagation networks

The most popular algorithm used to adjust the weights iteratively is called back propagation. This algorithm is widely used to perform supervised learning for a wide variety of applications. The main purpose of this algorithm is to teach the network to associate specific output values, also termed target values, with a given set of input and output data. Values obtained from output neuron are then compared to desired response. The difference generated is called as error signal. The error signals are then propagated in a backward direction to modify weights.

Back propagation algorithm is mainly consists of two passes, through different layers of network namely forward pass and backward pass. In forward pass the information flows through input neuron followed by hidden neurons and finally through output neurons. Finally, a set of output is produced as the actual response of the network. The synaptic weights of networks are fixed, when at the time of input the information flows in forward direction. During backward pass, synaptic weights are manipulated according to error-correction rule.

The error back propagation algorithm is also defined as simply back-prop, discussed in literature. A typical feed-forward back-propagation neural network is shown in Fig. 2.2, in which a neuron in any layer is connected to all neurons in the previous layer. The information flows through the network continuously in a forward direction, from left to right and on a layer-by layer basis.

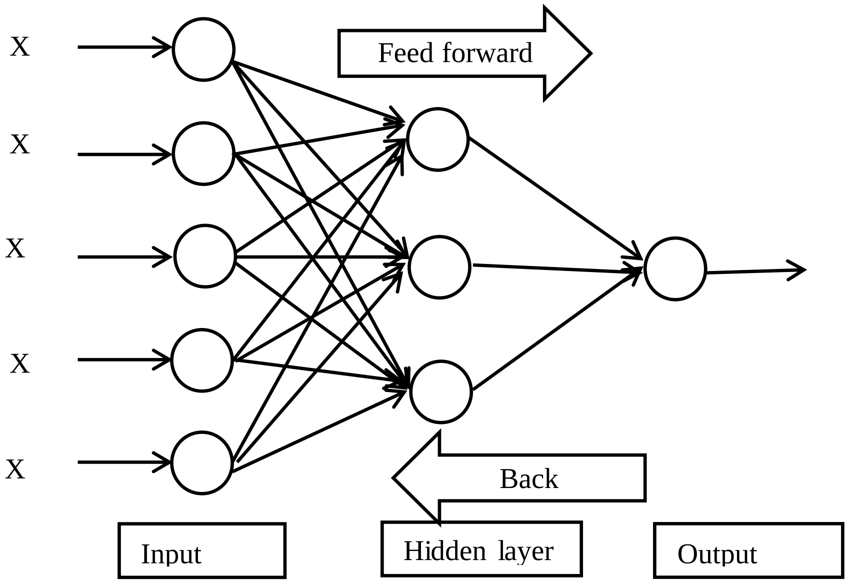

Fig. 2.2 Back-propagation networks

2.5.2 Applications of artificial neural networks to predict dust concentration

The ANN has become a more research interest from past two decades and is being successfully applied across various problem domains in the areas of medicine, engineering, science and finance. ANNs are nonlinear data driven self-adaptive approaches. ANN is powerful tool for modeling, especially when the data relationship is unknown. ANNs can identify and learn interrelated patterns between input data and corresponding output data. After training, ANNs can be used to predict output of new input data. Thus, they are ideally suited for modeling of agricultural data, which are known to be complex and often nonlinear.

Mohebbi et al. (2006) determined the particulate dispersion from Kerman Cement Plant, Iran. An Eulerian model, Gaussian plume model and an Artificial Neural Network were used to predict the concentration of PM10. Input to models were meteorological factors, source related factors and surface roughness and emission rate to estimate pollutant concentration from continuous sources. Performances of these models were compared with measured data. Average Absolute Percent Deviation (AAPD) parameters for different models (Eulerian model, Gaussian model and ANNs) were 25.53%, 15.38% and 5.91% respectively. Good agreement between field data and Eulerian model, Gaussian plume model and ANNs predicted values showed that these models can be powerful models for predicting particle concentration for downwind of a dust source. Gaussian plume model or ANNs gave more accurate values between 400 and 2,900m distances.

Lokman (2007) carried out a study on impact of air pollutants (SO_2 and Particulate Matter), which were released from Zonguldak Coalmine in Turkey. In his study, ANN method was used to predict SO_2 and PM10 concentrations from two different stations. Input data used for analysis in ANN method was meteorological data, past data from observed SO_2 and PM10 dust concentration. SO_2 and PM10 concentration data was for a 24 hour period at two sites for 3 months. All parameters are shown in Table 2.3 with their descriptive statistics.

Table - 2.3 Target and input variables considered in the neural network models (Lokman HakanTecer, 2002)

Parameters	**Unit**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
SO_2_BE (Target)	$\mu g/m^3$	013.00	196.00	064.352	35.993
MP_BE (Target)	$\mu g/m^3$	002.00	335.00	070.238	67.629
SO_2_CC (Target)	$\mu g/m^3$	013.00	299.00	091.137	53.246
MP_CC (Target)	$\mu g/m^3$	004.00	579.00	099.331	97.830
$SO_{2(t-1)}$_BE	$\mu g/m^3$	013.00	196.00	064.577	36.283
$PM_{2(t-1)}$_BE	$\mu g/m^3$	002.00	335.00	070.029	67.394
$SO_{2(t-1)}$_CC	$\mu g/m^3$	014.00	299.00	091.316	53.058
$PM_{2(t-1)}$_CC	$\mu g/m^3$	004.00	579.00	099.997	98.799
Pressure	mb	978.00	1018.00	1000.302	06.196
Cloudiness	x/10	000.00	010.00	004.771	03.200
Relative humidity	%	030.00	097.00	074.958	13.317
Wind speed mean	m/s	000.00	008.00	002.205	01.094
Wind speed Max	m/s	002.00	024.00	008.038	03.680
Temperature Max	°C	000.10	035.20	011.391	10.024
Temperature Mean	°C	-000.30	002.90	001.412	00.720
Temperature Min	°C	-004.40	024.30	007.584	07.577

2.6 Multiple Regression Analysis

Multiple Regression Analysis is a statistical technique used to analyze the relationship between a single independent variable and several independent variables. General regression equation is stated as follows:

$$Y = b_0 + b_1v_1 + b_2v_2 + \ldots\ldots b_nv_n \ldots\ldots\ldots\ldots\ldots \text{Equation (9)}$$

where,

Y = Predicted value

b_o = Intercept (Constant value)

b = Regression coefficient

v = Independent variable values

Generally, statistical analysis is classified into univariate, bivariate and multivariate techniques. Univariate method uses arithmetic mean. Correlation and simple regression analysis are used in the method of bivariate. Multivariate analysis is related to examination of more than two variables (Hair et al., 2010). Recently, the most commonly used multivariate statistical models for environmental analysis are Cluster analysis, Principal component analysis, Factor analysis, Multiple linear regression analysis (Kanade and Gaikwad, 2011).

Stepwise estimation is the most popular sequential approach for variable selection. This approach allows researcher to examine the concentration of each independent variable on the regression model. Independent variable with the greatest contribution needs to be added first. Independent variables are often selected for inclusions based on their incremental contribution over variables already available in the equation (Roy et al., 2011).

Multiple regressions are commonly used for identifying the relationship between single variable and several predictor variables. Multiple regression analysis used to solve important research problems including environmental prediction problems. This technique is used for various air pollution problems such as determination of tropospheric ozone, TSP, PM10, PM2.5, etc., (Sousa, 2010).

Bhanu Pandey et al. (2014) have studied assessment of air pollution by sulphur dioxide, nitrogen dioxide and particulate matter to environment from coalmines of Jharia, India. Multivariate statistical models such as Cluster Analysis (CA), Principal Component Analysis (PCA) were used for assessing the pollutants from coal mining. Sulphur dioxide, nitrogen dioxide and particulate matter were varying from season to season. In winter season, PM becomes more pollutant and less pollutant in rainy season. SPM found in winter season was about 500µg/m^3. Nitrogen dioxide value was about 80µg/m^3, which became lesser in other seasons.

Erol et al. (2013) examined quartz content from respirable dust in working faces of coal mines and evaluated the risk of getting pneumoconiosis among crew working near coal faces. Dust samples were collected using MRE 113A dust sampler and quartz content of dust was determined using FTIR instrument. Mean respirable dust concentration at most of the coal faces were found to be above the permissible limits. Analysis of variance (ANOVA) was performed to determine the effect of workplace and seam characteristics on dust levels and they found a remarkable variation of respirable dust and quartz content in different seams.

From the extensive survey of literature, the review can be summarized as follows:

- Dust generation and its dispersion has been the major concern in ambient air quality in surface mines. Major mining activities in opencast mines range from drilling to processing of end product that primarily contribute Particulate

Matter (PM), dominantly PM10, leading to the problem of air pollution and related health hazards.

- Many researchers have tried to predict the dust dispersion models in general. The most commonly used dust dispersion models developed by USEPA are over-predicting the amount of PM10 from the mining operations by more than a factor of two (U.S. EPA, Modeling Fugitive Dust Phase I, 1994) (Cole and Zapert, 1995).
- So, there is great need for developing a mathematical model, which determines dust dispersion from mining operations in various formations. Such a model would accurately predict the dust emission and concentration as a function of various parameters such as operational parameters, rock properties and meteorological parameters, thus facilitating accurate control of dust emission and concentration.
- The present research study is limited to drilling activity. An attempt is made to develop dust emission and dispersion models based on field investigations.

CHAPTER - 3

FIELD INVESTIGATIONS

To develop a mathematical model to predict dust dispersion from drilling operations in surface mines, field investigations were carried out in total eight opencast mines / quarries. Among them, three are opencast coal mines, two are limestone mines and three are granite quarries. During the field investigations, large amount of data was collected for the development of dust prediction models. Description of the case studies and the methodology of airborne dust monitoring with a brief description of air pollution monitoring equipment used are presented in this chapter. The methodology used to develop the dust prediction models is also explained.

3.1 Dust Monitoring

Field investigations included monitoring of meteorological parameters and Ambient Air Quality (AAQ) for measuring the dust concentrations in eight mining projects. Monitoring and analysis were carried out as per the methods prescribed by the Central Pollution Control Board (CPCB) / National Ambient Air Quality Standards (NAAQS) guidelines, using different dust monitoring instruments as listed in Table - 3.1.

Table - 3.1 Equipment used for dust monitoring and meteorological parameters

Sl. No.	Name of Equipment	Code / Symbol	Type of Dust
1	Personal Dust Samplers (4 units)	R1, R2, R3,R4	Respirable dust (PM10 and PM2.5)
2	Point Samplers (2 units)	P1, P2	PM10 and PM2.5
3	Meteorological monitoring station	Used to meteorological parameters	

3.2 Description of Dust Monitoring Equipment

Dust monitoring was carried out using Personal dust samplers (Casella Tuff Personal Sampling Pumps by Casella Cel, U.K) commonly called as TUFF samplers, Point Samplers (Polltech Instruments Pvt. Ltd., PEM-ADS 2.5µ/10µ), Meteorological Monitoring Station (Envirotech Instruments Ltd.). Technical details of all the equipments are given below.

3.2.1 Personal dust samplers

Personal dust samplers or TUFF samplers were used to monitor the dust concentration of Respirable Particulate Matter (PM10 and PM2.5). This instrument is battery operated and the battery life is 24 hours for sampling at a constant flow rate of 1.1 liters per minute (LPM) (Fig. 3.1). TUFF samplers were used to monitor the dust concentration during drilling operation. These samplers were fixed at different distances from drilling operation, fixed to ranging rods at a height of 2m from the ground. Sampling duration was 1, 8, 16 or 24 hours based on the running time of drilling machines. Finally, all samples were calibrated to 24hour sampling according to CPCB / NAAQS prescribed protocols. The filter paper was replaced for each sampling.

Basis for air sampling is to sample a volume of air through a suitable sampling medium usually paper or solid filter media (Glass Microfiber Filter (GFA), which is used in TUFF samplers) for Particulate Matter. The volume of sampled air is measured and concentration of dust is calculated and expressed as mg/m^3 or µg/m^3.

Specifications of TUFF Personal Air Sampler

Flow rate **:** 4.5 LPM to 5 LPM (for PM10 it is 1.1 LPM)
Particle Size **:** Suspended Particulate Matter (SPM) and PM10
Recommended Filter **:** Glass Microfiber Filter (GFA)
Sampling Time **:** From 1 hour to 24 hours

Sampling control : Manual

Power Requirements : Battery operated (removable 4.8V Nickel Metal Hydride (NiMH) rechargeable cells with a 2.7Ah capacity)

Size : 133mm x 87mm x 47mm

Weight : 480gm

The Respirable dust standard set by the Central Pollution Control Board (CPCB) recommends a 10µm cut-off size for respirable dust measurements. The filter cassette and the type of filter paper used in the TUFF Personal air sampler provide the cut-off at 10µm for particulate matter present in the ambient air.

Fig. 3.1 Respirable dust sampler / Tuff sampler

3.2.2 Point samplers

Point samplers / Ambient fine dust samplers (Polltech Instruments Pvt. Ltd., PEM-ADS 2.5µ/10µ) were used for monitoring PM10 particulates in the ambient air (Figs. 3.2 and 3.3).

Fig. 3.2 Ambient point samplers

Fig. 3.3 Inner view of ambient point sampler

Ambient air is drawn at a constant volumetric flow rate of 16.7 LPM through a specially designed "Sampling Inlet", which separates particles larger than 10μm and allows smaller particles to enter into an internal particle size separator (USEPA WINS impactor), where particulate matter in PM10 size range is collected on a Polytetra flurothylene (PTFE) filter over the specified sampling period. Each filter is weighed before and after sample collection to determine the net mass of PM10 collected on the filter paper. The mass concentration of PM10 particles in ambient air is computed by dividing the total mass of dust collected by the volume of sampled air and is expressed in terms of $\mu g/m^3$ or Parts Per Million (PPM). If the Ambient fine dust sampler is used without USEPA WINS impactor (2.5µ cut stage), the instrument is a standard reference method for particulate matter of less than 10µm.

Specifications of Point Samplers used:

Flow Rate Meter	**:**Flow in liters/min (LPM) on digital display and flow rate is 16.7LPM
Flow Control System	**:**Electronic sample air flow rate control system based on flow control proportioning valve to operate over a pressure drop of clean filter + 60mm Hg. Flow regulation better than ±3% over 24 hour period at a rate of 16.7 LPM
Filter Media	**:**PTFE 46.2mm filter for PM2.5and glass microfiber filters (GF/A) for PM10measurement
PM-2.5 Size Separator	**:**US EPA PM2.5WINS impactor
Clock/Timer System	**:**Programmable real time control system with automatic start, stop, digital display of date and time of sampling
Temperature Sensors	**:**For ambient temperature and filter temperature, range -5 to 50°C with resolution of 0.1°C
Pressure Sensor	**:**Range 600 to 800 mm Hg. Resolution 1 mm Hg
RS232 Serial Output	**:**For downloading the data storage module
Vacuum Pump	**:**A diaphragm type pump with AC motor
Power	**:**230 V AC ± 10% 50Hz
Height of Sampling Inlet	**:**2m above ground level with stand
Weight	**:**25kg

3.2.3 Meteorological monitoring station

The dust particulates dispersion in air is influenced by the movement and characteristics of air mass into which they are emitted. If the air is calm, particulates cannot disperse then the concentration of these pollutants builds up. Conversely, if a strong turbulent wind is blowing, particulates emitted / generated will be rapidly dispersed into the atmosphere and result in lower concentrations near the pollution source. Therefore, the reliable information of wind movement is an essential requirement for air quality management. The information regarding the extent of dust dispersion and the resultant Ground Level Concentration (GLC) depends upon local meteorological parameters such as wind speed, wind direction, atmospheric turbulence or stability and the mixing height, etc. Clearly, an objective assessment of GLC and its likely impact on the local environment can only be made after obtaining reliable local wind data. Mathematical modeling to predict air-quality implications requires reliable information on the local wind trends and stability conditions at different times of the day and seasons of the year. Envirotech Wind Monitoring System (WM271) was used for generating the micro-meteorological data required for this research work. The WM271 is the fourth generation Wind Monitoring System produced by Envirotech Instruments (Fig. 3.4).

Fig. 3.4 Meteorological monitoring station

Specifications of Meteorological Monitoring Station (WM271)

The standard WM271 system is supported with Sensors for Wind Speed, Wind Direction, Temperature, Relative Humidity, Solar Radiation and Rainfall.

Wind Speed : Range 0 to 100 km/hour

Wind Direction : Range 0 to 360° with 1° resolution

Temperature & RH : Range 0 to 50^{O}C with resolution of 0.1 ^{o}C and 0 to 100% RH with 1% resolution

Solar Radiation : Li-Cor Model 096 Pyranometer with sensitivity of 90µA per 1000Wm

Barometric Pressure : Met one model 091 with an accuracy of ±0.04 in Hg (±1.35mbar) this sensor is being introduced with WM271

Rainfall : Range 0 to 50 mm/hour with 0.5mm resolution

Data Access : Built-in firmware supports land-line and GSM Modems for Remote data access. The WM271 can also be interfaced directly to a standard RS232 port (COM port) of a computer for data transfer

Software : Windows XP compatible, Envirotech Met-Log software is provided with the WM 271 for data download to a computer and analysis

Power Requirement : The WM 271 is powered by a Rechargeable Ni-MH battery Pack that can keep the system operating for about 20 hours. The standard system is supplied with a mains power based Charger. An optional Solar Panel based charger making the Instrument completely independent of mains power is available as an accessory

3.3 Methodology for Dust Monitoring

Airborne respirable dust monitoring was carried out during drilling operation in eight opencast mines using four personal dust samplers and two ambient point samplers. Meteorological station was installed in mine premises and hourly basis readings were collected. Instruments were placed at different distances towards down wind direction during drilling operation and initially one instrument was placed towards up wind direction to identify the background concentration of operation. Same procedure was followed on each day for monitoring during field studies in all other mines. In order to assess the influence of rock properties on dust emission, rock samples were collected from the field at different locations and tests were conducted in the laboratory to determine required physico-mechanical properties.

3.3.1 Determination of rock properties

Rock properties play a major role in emanating the dust during drilling operation in surface mines. Some rock samples were collected during the field investigations from different locations of the mines. Various tests were carried out in the laboratory to determine different rock properties of the collected samples.

3.3.1.1 Determination of moisture content

Moisture content test was carried out in the laboratory as per IS: 2720 (part II)-1973. To determine moisture content present in the drill cuttings, the sample was placed in an oven, which was capable of maintaining temperature of $105^{o}C$ for a period of at least 24 hours. Initially, the sample was placed in a container, made up of non-corrodible material and its mass was taken (M1). Later, container comprising drill cuttings was placed in an oven at a temperature of $105^{o}C$ for a period of 24 hours. After 24 hours, container having drill cuttings was taken out and allowed for cooling at room temperature. Finally, weight of container with dried drill cuttings (M2) was taken. Also, final weight of dried drill cuttings was taken. Finally, moisture content value was expressed in percentage. Following formula was used to determine the moisture content in different types of drill cuttings samples:

Moisture content = (Mass of water content (M1-M2) / Dried drill cuttings weight)*100 %
…………Equation (3.1)

3.3.1.2 Determination of density

Density of different rock samples were determined as per ISRM (International Society for Rock Mechanics) suggested method (Part-1, No. 2). Initially, container (glass) with some amount of water was chosen and difference of water level before and after dropping the rock sample was observed for finding volume of the sample (Fig. 3.5). Rock mass of the sample was determined by weighing method before dropping into water container. Finally, density of rock sample was determined by using the following formula:

Density $= \frac{\mathrm{m}}{V}$ ………………Equation (3.2)

where,

ρ (rho) = Density of the rock sample (g/cc)
m = Mass (g)
V = Volume (cc)

Fig. 3.5 Experimental set up to determine density

3.3.1.3 Determination of Protodyakonov's Strength Index

Compressive strength of rocks can be determined using ISRM suggested methods. But, preparation of samples as per ISRM standards for coal and sandstone is very difficult, so the compressive strength of coal and sandstone was determined indirectly using Protodyakanov's strength index and Point load strength index.

Protodyakonov's Strength Index (PSI) is a way of characterizing rock strength, which has immense possibility for practical implementation in rock cutting and drilling. It also gives an approximate value of uniaxial compressive strength of rock.

The Protodyakonov strength scale finds wide use in Russia, Poland and other East European countries. This scale assigns a series of numbers for rocks in ascending order of strength, ranging from 1 to 20. This method was suggested by Prof. M.M. Protodyakonov (Sr), in 1907. Since then the method has found wide applications in rock engineering. The strength Index (hardness coefficient) essentially a measure of the strength of rock under uniaxial compression and is expressed in units of 100kg/cm^2. The Protodyakonov strength number 'f' according to Prof. M.M. Protodyakonov (Sr) is the instantaneous compressive strength in kg/cm^2 divided by 100, i.e., f=C/100, where 'C' is compressive strength in kg/cm^2 of cubical rock samples.

Samples were collected in the form of lumps during field investigations from different benches of mines. Each sample was broken with a hammer and 5 test specimens consisting of fragments of 20 to 40mm in size and of each 10 to 20 cm^3 are picked. Each test specimen was placed in a cylinder of 76mm internal diameter and was pounded with a 2.4kg drop weight falling from a height of 0.6m. The number of impacts 'n' to which these test specimens are subjected is 5. After pounding all the five specimens, the test material was sieved on a 500 micron sieve. Fines that pass through 500 microns sieve were poured into the tube of a volume meter and the height of powder in volume meter (l) was recorded. Protodyakonov's strength index 'f' was determined by the following equation

$$f = \frac{20*n}{l} \qquad \text{---------Equation (3.3)}$$

where,

f = Protodyakanov's strength index

n = Number of impacts

l = Height of powder in volume meter (mm)

Fig. 3.6 Experimental setup of protodyakonov's strength index

3.3.1.4 Determination of Point Load Strength Index

Point load strength index is determined on irregular samples by keeping rock sample between two conical platens of Point load strength index apparatus. The following formula gives the Point Load Strength Index.

$$\text{PLI} = \frac{\text{P}}{d*2} \qquad \text{----------Equation (3.4)}$$

where,

PLI = Point load Strength Index

P = Load at failure (KN)

D = Distance between conical platens (mm)

Generally compressive strength is 24 to 26 times of Point load strength index.

Compressive strength of rocks plays an important role in emanating dust emission during drilling in many opencast mines and underground mines. Determination of compressive strength in theory is a simple procedure, in practice, it is among the expensive and time consuming test, because sample preparation based on the existing standards and conducting the tests by using compressive hydraulic jacks. Based on the suitability of the sample, tests were carried out to determine compressive strength, Protodykanov's Strength Index or Point Load Strength Index was used. Finally, the strength values are expressed in terms of compressive strength uniformly.

3.3.1.5 Determination of Rebound Hardness Number

Rebound hardness number is a useful measurement in assessing the nature of rock mass. Schmidt rebound hardness number is a non-destructive test, which gives rebound hardness number. This test was determined as per ISRM suggested methods (Part III). The mechanism of operation is simple in Schmidt Rebound Hardness hammer instrument, in which a hammer was released by means of spring and it indirectly impacts against the rock surface through a plunger (Fig. 3.7). The rebound distance of the hammer is then read directly from numerical scale ranging from 10-100. According to ISRM suggested method, twenty rebound values from single impacts separated by at least a plunger diameter should be recorded and the upper ten values are averaged to get rebound hardness number.

Fig. 3.7 Experimental setup of the Schmidt rebound hardness

3.3.1.6 Determination of silt content

Silt content test was carried out as per IS: 2386 (part III), 1973. Silt content in the drill cuttings has direct influence on the effectiveness of the dust generation and emission. To find silt content in the drill cuttings, the following procedure was followed. In a 500ml measuring cylinder, the dust particles were pored (consolidated by shaking) until they reach the 200ml mark. Then the cylinder was filled with water and stirred. The following formula was used to find the silt content in the drill cuttings.

$$\text{Silt content} = \frac{X-Y}{Y} X\ 100 \qquad \text{......Equation (3.5)}$$

where,

X = Height of drill cuttings before pouring water into the cylinder (mm)

Y = Height of drill cuttings after pouring water in to the cylinder (mm)

3.4 Field Investigations

Field investigations were carried out in eight opencast mine / quarries. Among them, three were opencast coal mines, two were limestone mines and the remaining were granite quarries. Details of all case studies are discussed below.

3.4.1 Case study-1

First case study was taken up in Prakasam Khani Opencast-II (PKOC-II) Project, The Singareni Collieries Company Limited (SCCL), Manuguru area, Khammam District, Telangana State. The Singareni Collieries Company Limited (SCCL) is the only coal producing company in South India for more than 100 years. The Company had expanded its mining activities in Adilabad, Karimnagar, Warangal and Khammam districts of Telangana

State. PKOC-II project having area of 900hectares is located in the Manuguru area of Khammam District. It is situated between Latitudes 17° 55’ 34” to 17° 59’ 11” Latitude and 80° 43’ 57” to 80° 47’ 27” Longitude.

A broad view of PKOC-II mine is shown in Fig. 3.8. Benching method is adopted to remove overburden as well as coal in this mine. Overburden is fragmented using drilling and blasting. 250mm and 150mm diameter blastholes were drilled with wagon drills in sandstone and coal benches respectively (Fig. 3.9). Each blasthole is charged with Site Mixed Emulsion (SME) and initiated with shocktube detonators. Fragmented material is loaded with the help of shovels into dumpers and transported to dump yard. To monitor dust emission and concentration during drilling operation, field studies were carried out in different seasons.

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Fig. 3.8A

Fig. 3.8B

Fig. 3.8 Broad view of PKOC-II mine

Fig. 3.9 View of drilling operations in PKOC-II mine

3.4.1.1 Dust monitoring during drilling activity in PKOC-II mine

Airborne respirable dust studies were carried out during drilling in sandstone and coal benches using four personal air samplers and two ambient point samplers (Figs 3.10 and 3.11).

Fig. 3.10 Personal dust monitor near drilling activity in coal benches

Fig. 3.11 Ambient point samplers near drilling activity in coal benches

Blastholes were drilled at a penetration rate of 0.33m/min to 0.28m/min. The penetration rate was obtained by dividing the total length with duration of drilling. As discussed in methodology, dust monitoring equipments were placed at different locations from drilling operation. Dust samples were collected carefully and kept in closed containers in order to avoid any moisture variation. Samples were weighed accurately in the laboratory.

First phase of field investigations were carried out in summer and post summer seasons during June-July, 2013. During this period, total 40 samples were collected. Second stage of field investigations was carried out during winter season, i.e., during the period November–December, 2013 and during this period in total 30 samples were collected. Third stage of field investigations were carried out during winter season in November–December, 2014 and during this period in total 22 samples were collected.

Meteorological data such as temperature, relative humidity and wind speed were obtained from meteorological station installed in the mine. Vertical dispersion coefficient **(σ_z)** and horizontal dispersion coefficient **(σ_y)** were determined based on downwind distance from the Pasquill-Gifford graphs developed by Chaulya et al. (1999). Other parameters are such as moisture content, silt content, density, PSI and rebound hardness number values were determined in the laboratory.

Among all the samples collected from PKOC-II mine, 30 samples were collected from coal benches, 20 from sandstone benches for the emission, which ranged between 0.051g/s and 0.794g/s. Detailed dust emission values obtained are given in the Table - 3.2 and Table -3.3. Similarly, 42 samples were collected for dust concentration which ranged between 110µg/m^3 and 352µg/m^3. Detailed dust concentration values along with other parameters are given in Tables - 3.4 and Table - 3.5.

Table - 3.2 Dust monitored in PKOC-II mine for emission rate in coal benches

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (gm/cm^3)	σc (MPa)	R	E (g/s)
1	250	0.33	02.8	28.0	1.26	18	23	0.708
2	250	0.33	20.8	33.0	1.27	16	22	0.498
3	150	0.28	17.8	26.0	1.24	15	23	0.392
4	250	0.33	20.2	28.0	1.24	17	20	0.581
5	250	0.33	18.0	22.2	1.26	17	19	0.452
6	150	0.28	15.0	24.5	1.25	17	22	0.339
7	250	0.33	07.9	32.0	1.25	20	21	0.682
8	250	0.33	08.3	30.0	1.26	17	21	0.684
9	150	0.28	10.2	29.0	1.22	18	22	0.525
10	250	0.33	07.9	33.0	1.25	16	23	0.719
11	250	0.33	08.5	30.0	1.25	17	23	0.721
12	150	0.28	10.4	28.5	1.24	16	23	0.509
13	250	0.33	18.0	25.0	1.24	18	20	0.543
14	250	0.33	18.0	22.2	1.26	18	19	0.556
15	250	0.33	18.8	30.0	1.26	17	23	0.537
16	150	0.28	15.0	24.5	1.25	16	22	0.355
17	250	0.33	07.9	32.0	1.25	17	21	0.682
18	250	0.33	08.3	30.0	1.26	18	21	0.678
19	150	0.28	10.2	29.0	1.22	17	22	0.525
20	250	0.33	07.9	33.0	1.25	20	23	0.679
21	250	0.33	08.5	30.0	1.25	20	23	0.620
22	150	0.28	10.4	28.5	1.24	17	23	0.439
23	250	0.33	16.0	25.0	1.24	17	20	0.567
24	250	0.33	18.0	22.2	1.26	17	19	0.517
25	150	0.28	15.0	24.5	1.25	17	22	0.332
26	250	0.33	07.9	32.0	1.25	18	21	0.682
27	250	0.33	08.3	30.0	1.26	17	21	0.794
28	150	0.28	10.2	29.0	1.22	17	22	0.492
29	250	0.33	07.9	33.0	1.25	18	23	0.779
30	250	0.33	08.5	30.0	1.25	20	23	0.721

Table - 3.3 Dust monitored in PKOC-II mine for emission rate in sandstone benches

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate
	d (mm)	P (m/min)	m (%)	s (%)	ρ (gm/cm^3)	σc (MPa)	R	E (g/s)
1	250	0.33	18.6	41.1	2.25	38	34	0.077
2	250	0.33	17.0	26.3	2.28	42	29	0.051
3	150	0.28	12.5	49.6	2.25	49	31	0.154
4	250	0.33	08.1	32.6	2.28	38	33	0.215
5	250	0.33	09.4	37.8	2.35	39	32	0.295
6	150	0.28	10.2	39.3	2.27	42	28	0.183
7	250	0.33	08.2	29.2	2.39	41	27	0.279
8	250	0.33	08.3	31.9	2.25	41	34	0.158
9	150	0.28	06.2	65.3	2.38	39	34	0.443
10	150	0.28	12.5	49.2	2.25	42	26	0.324
11	250	0.33	05.1	32.2	2.38	44	31	0.265
12	250	0.33	09.4	37.3	2.25	49	34	0.175
13	150	0.28	02.0	29.3	2.37	47	31	0.119
14	250	0.33	09.4	37.3	2.25	44	35	0.155
15	150	0.28	02.0	39.0	2.37	49	34	0.152
16	250	0.33	08.2	29.0	2.29	47	32	0.179
17	250	0.33	08.3	31.0	2.25	48	29	0.238
18	150	0.28	04.2	45.0	2.28	49	28	0.331
19	150	0.28	12.5	29.0	2.35	47	27	0.324
20	250	0.33	09.4	37.0	2.35	49	29	0.225

Table - 3.4 Dust monitored in PKOC-II mine for concentration in coal benches

Sl. No	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration
	d (m)	T (^{o}C)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (µg/m^3)
1	15	37.5	21.5	1.8	11.0	18	0.881	340
2	25	35.5	41.5	2.1	07.5	14	0.788	290
3	20	37.5	38.9	2.5	07.5	14	0.778	338
4	18	37.5	38.9	1.5	11.0	18	0.807	330
5	30	37.5	38.9	2.3	07.5	14	0.935	310
6	26	36.8	38.7	2.4	07.5	14	0.878	352
7	27	33.2	50.5	1.8	11.0	18	0.958	320
8	55	33.6	52.1	2.1	07.5	14	0.887	226
9	50	33.2	52.4	2.5	07.5	14	0.774	180
10	32	30.3	60.4	1.5	11.0	18	0.961	210
11	45	30.3	52.4	2.3	07.5	14	0.816	185
12	55	30.3	60.4	2.4	07.5	14	0.974	220
13	100	33.3	50.4	1.8	11.0	18	0.667	110
14	55	30.3	60.4	1.1	07.5	14	0.783	120
15	78	35.3	60.4	2.5	07.5	14	0.911	235
16	18	37.5	38.9	1.5	11.0	18	0.587	230
17	30	37.5	38.9	2.3	07.5	14	0.935	310
18	26	36.8	38.7	2.4	07.5	14	0.718	302
19	27	33.2	50.5	1.8	11.0	18	0.858	220
20	45	33.6	52.0	2.1	07.5	14	0.887	226
21	50	33.2	52.4	2.5	07.5	14	0.674	160
22	32	30.3	60.4	1.5	11.0	18	0.861	180

Table - 3.5 Dust monitored in PKOC-II mine for concentration in sandstone benches

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration
	d (m)	T (^oC)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C ($\mu g/m^3$)
1	21	24.0	54.2	2.8	7.0	14	0.877	190
2	13	24.0	54.0	2.2	7.5	14	0.865	170
3	25	29.0	50.0	2.7	7.5	14	0.706	120
4	42	30.0	46.3	2.6	7.0	14	0.888	266
5	29	30.0	44.0	2.5	7.5	14	0.807	252
6	60	30.0	43.0	2.9	7.5	14	0.705	150
7	56	30.0	46.4	2.8	7.0	14	0.881	195
8	10	30.0	46.0	2.2	7.5	14	0.828	215
9	15	29.0	50.1	2.7	7.5	14	0.993	330
10	70	30.0	33.0	2.8	7.0	14	0.533	126
11	75	25.0	49.3	2.3	7.0	14	0.889	126
12	80	25.0	49.1	2.2	7.0	14	0.881	120
13	20	21.0	42.1	2.5	7.5	14	0.859	177
14	25	21.0	32.1	2.1	7.5	14	0.814	188
15	30	28.9	52.0	2.1	7.0	14	1.161	270
16	56	30.0	46.0	2.8	7.0	14	0.931	195
17	10	30.0	46.5	2.2	7.5	14	0.828	215
18	15	29.0	50.0	2.7	7.5	14	0.793	230
19	35	28.9	52.8	2.4	7.5	14	0.871	215
20	40	28.8	44.6	2.2	7.5	14	0.952	210

3.4.2 Case study-2

Second case study was taken up in Bhuvaneshwari Opencast Project (BOP), Talcher area of Mahanadi Coalfields Limited (MCL), a subsidiary of Coal India Limited (CIL). Broad view of Bhuvaneshwari mine is shown in Fig. 3.12. It is having an area of 7.23km^2 and located between Latitudes 19^{o}43’30” -- 19^{o}46’44” and Longitudes 83^{o}49’11” -- 83^{o}52’38”.

Benching method is being adopted to remove overburden and coal in this mine. Overburden was fragmented using drilling and blasting. Blastholes were drilled with wagon drills, charged with Site Mixed Slurry (SMS) and initiated with shocktube detonators. Fragmented material was loaded with the help of shovel into dumpers and transported to dump yard. Coal was removed by surface miner and extracted coal was loaded with the help of pay loader into tippers and transported to stockyard.

Fig. 3.12A

Fig. 3.12B

Fig. 3.12 Broad view of Bhuvaneswari open cast coal mine

3.4.2.1 Dust monitoring during drilling activity in BOP mine

Ambient Air Quality monitoring was performed to measure dust concentrations from drilling activity at Bhuvaneswari Opencast Mine of Talcher Coalfields. Meteorological parameters were collected using meteorological station. Four units of Personal dust samplers and two units of Ambient point samplers were placed around the wagon drill at different distances as shown in Fig. 3.13. 150mm and 250mm diameter drilling machines were used to drill blastholes in different benches. These drills were operated at a penetration rate of 0.28m/min to 0.33m/min. **σ** (z) and **σ** (y) were obtained from Gifford Pasquill graphs.

Dust monitoring distances varied from 5m to 70m from drilling machine. In total, 41 samples (21 from coal benches, 20 from sandstone benches) were collected for emission values, which ranged between 0.114g/s and 1.009g/s. Details of dust emission values obtained are given in Tables - 3.6 and 3.7. Similarly, 40 samples were collected for concentration and the values ranged between 125µg/m^3 and 510µg/m^3. Details of dust concentration values obtained are given in Tables - 3.8 and 3.9.

Fig. 3.13A

Fig. 3.13B

Fig. 3.13 Personal dust monitor near drilling machine

Table - 3.6 Dust monitored in Bhuvaneshwari mine for emission rate in coal benches

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate
	d (mm)	P (m/min)	m (%)	s (%)	ρ (gm/cm^3)	σc (MPa)	R	E (g/s)
1	250	0.33	08.3	31.0	1.24	16	23	0.650
2	150	0.28	10.2	30.0	1.25	18	23	0.565
3	150	0.28	07.1	39.0	1.25	19	20	0.845
4	150	0.28	05.6	39.8	1.24	16	19	1.003
5	150	0.28	09.1	34.0	1.24	17	19	0.652
6	150	0.33	07.4	38.0	1.26	20	19	0.892
7	150	0.28	10.3	28.3	1.25	17	19	0.565
8	150	0.28	07.8	36.2	1.29	16	18	0.695
9	250	0.33	02.4	46.0	1.26	18	18	1.099
10	150	0.28	07.1	49.0	1.25	19	20	1.022
11	150	0.28	07.6	39.8	1.24	16	19	0.928
12	150	0.28	08.9	34.0	1.24	17	19	0.642
13	150	0.33	07.4	38.0	1.26	20	19	0.892
14	150	0.28	07.9	38.8	1.25	17	19	0.665
15	150	0.28	11.5	34.0	1.24	17	19	0.552
16	150	0.33	07.4	38.0	1.26	20	19	0.792
17	150	0.28	07.9	38.8	1.25	17	19	0.617
18	150	0.28	07.8	36.2	1.29	16	18	0.649
20	150	0.28	07.1	39.9	1.25	19	20	0.792
21	150	0.28	07.6	39.8	1.24	16	19	0.654

Table - 3.7 Dust monitored in Bhuvaneshwari mine for emission rate in sandstone benches

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate
	d (mm)	P (m/min)	m (%)	s (%)	ρ (gm/cm^3)	σc (MPa)	R	E (g/s)
1	250	0.33	14.2	54.2	2.35	38	31	0.357
2	250	0.33	12.0	56.3	2.38	49	34	0.333
3	150	0.28	12.5	69.2	2.35	45	35	0.324
4	250	0.33	08.1	32.3	2.38	43	33	0.165
5	250	0.33	09.4	37.4	2.35	46	36	0.125
6	150	0.28	10.2	49.5	2.37	43	35	0.114
7	250	0.33	08.2	29.2	2.39	46	31	0.179
8	250	0.33	08.3	31.3	2.35	47	35	0.118
9	150	0.28	11.2	55.2	2.38	48	35	0.143
10	250	0.33	07.9	32.1	2.35	42	31	0.216
11	250	0.33	08.5	30.2	2.37	44	26	0.310
12	150	0.28	10.4	58.5	2.39	47	28	0.382
13	250	0.33	16.0	55.0	2.38	43	27	0.377
14	250	0.33	02.4	50.2	2.37	47	35	0.370
17	250	0.33	08.3	39.1	2.38	45	35	0.166
18	250	0.33	07.9	33.2	2.37	47	35	0.179
20	250	0.33	08.3	31.3	2.37	46	31	0.158

Table - 3.8 Dust monitored in Bhuvaneshwari mine for concentration in coal benches

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration
	d (m)	T (^oC)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C ($\mu g/m^3$)
1	40	30.3	60.4	1.5	7.5	14	0.803	125
2	45	30.3	60.4	2.3	7.5	14	0.795	126
3	25	35.5	41.5	2.4	7.5	14	0.653	220
4	29	36.8	38.7	2.5	7.5	14	0.859	315
5	33	37.9	36.0	2.2	7.5	14	0.835	325
6	34	36.8	38.7	2.3	7.5	14	0.854	335
7	38	37.9	36.0	2.3	7.5	14	0.691	252
8	05	27.0	72.0	2.5	7.5	14	0.959	155
9	06	27.0	72.0	2.9	7.5	14	1.306	320
10	09	27.0	72.0	2.8	7.0	14	1.217	252
11	10	27.0	72.0	2.2	7.5	14	1.159	220
12	12	27.0	72.0	2.7	7.5	14	1.187	210
13	13	25.0	50.0	2.6	7.0	14	1.201	252
14	22	25.0	50.0	2.5	7.5	14	1.202	245
15	18	25.0	50.0	2.9	7.5	14	0.914	220
16	12	27.0	72.0	2.2	7.5	14	1.329	250
17	12	27.0	72.0	2.7	7.5	14	1.926	510
18	16	25.0	50.0	2.6	7.0	14	1.201	252
19	15	25.0	50.0	2.5	7.5	14	1.290	365
20	10	27.0	72.0	2.7	7.5	14	1.294	250
21	13	25.0	50.0	2.6	7.0	14	1.201	251

Table - 3.9 Dust monitored in Bhuvaneshwari mine for concentration in sandstone benches

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration
	d (m)	T (^{o}C)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C ($\mu g/m^3$)
1	40	28.8	44.6	2.2	07.5	14	0.752	140
2	45	28.8	44.6	2.2	07.5	14	0.935	200
3	50	27.0	45.3	2.1	07.5	14	0.972	195
4	55	27.0	45.3	2.2	07.5	14	0.971	220
5	05	43.0	53.1	3.2	12.0	20	0.772	320
6	10	43.0	53.1	3.2	12.0	20	0.747	310
7	15	43.0	53.1	3.2	12.0	20	0.675	280
8	20	43.0	53.1	3.2	12.0	20	0.603	250
9	10	43.0	53.1	3.2	12.0	20	0.518	215
10	20	43.0	53.1	3.2	12.0	20	0.494	205
11	40	42.0	52.9	3.4	12.0	20	0.628	245
12	50	42.0	52.9	3.4	12.0	20	0.722	282
13	65	42.0	52.9	3.4	12.0	20	0.628	245
14	70	42.0	52.9	3.4	12.0	20	0.743	290
15	25	42.0	52.9	3.4	12.0	20	0.571	223
16	35	42.0	52.9	3.4	12.0	20	0.551	215
18	15	43.0	53.1	3.2	12.0	20	0.625	280
19	18	43.0	53.1	3.2	12.0	20	0.613	250
20	10	43.0	53.1	3.2	12.0	20	0.598	215

3.4.3 Case study-3

Third Case Study was taken up in Samaleswari Opencast Project (SOP) of IB Valley of Mahanadi Coalfields Limited (MCL), Orissa, A subsidiary of Coal India Limited (CIL). Fig. 3.14 shows the view of Samaleswari Opencast Project. It is situated between Latitudes $20^{o}56'35''$ to $20^{o}58'40''$ and Longitudes $85^{o}06'30''$ to $85^{o}08'40''$. In SOP, the lithology consists of mainly soil, sandstone and coal. Overburden is fragmented by drilling and blasting. Coal is being extracted using surface miners and extracted coal was transported to coal stock and then to coal handling plant.

Fig. 3.14A

Fig. 3.14B

Fig. 3.14 Overall mine view of Samaleswari OCP

3.4.3.1 Dust monitoring during drilling activity in SOP mine

Field investigations were carried out in April-May, 2014. Three units of Personal dust samplers and two units of Point samplers were placed around drilling machine (Fig. 3.15). Drill machines are having diameter of 150mm and 250mm. These drills are operated at a penetration rate of 0.28m/min to 0.33m/min.

Dust monitoring distances varied from 5m to 70m from drilling source. In total, 40 samples (25 from coal benches and 15 from sandstone benches) were monitored for emission at the source of dust, which were ranging between 0.017g/s and 0.911g/s. Detailed dust emission values obtained are given in the Tables-3.10 and 3.11 along with other parameters. Similarly, for concentration, 40 samples (21 from coal benches and 19 from sandstone benches) were collected, which ranged between 111µg/m^3 and 562µg/m^3. Detailed dust concentration values obtained are given in Tables - 3.12 and 3.13. Meteorological parameters such as temperature, humidity and wind velocity were monitored using meteorological station. **σ** (z) and **σ** (y) were obtained from Gifford Pasquill graphs.

Fig. 3.15 Personal dust samplers near drilling machine in SOP

Table - 3.10 Dust monitored in Samaleshwari mine for emission in coal benches

Sl. No	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate
	d (mm)	P (m/min)	m (%)	s (%)	ρ (gm/cm^3)	σ (MPa)	R	E (μg/m^3)
1	250	0.33	02.8	22.5	1.25	15	23	0.612
2	250	0.33	08.5	21.9	1.25	18	23	0.512
3	150	0.28	24.3	22.1	1.24	21	23	0.162
4	250	0.33	16.0	25.0	1.24	20	20	0.412
5	250	0.33	18.0	22.2	1.26	19	19	0.410
6	150	0.28	15.3	24.5	1.25	17	19	0.481
7	250	0.33	07.9	32.0	1.25	15	19	0.722
8	250	0.33	08.3	30.0	1.26	16	19	0.719
9	150	0.28	12.2	27.3	1.22	13	18	0.678
10	250	0.33	11.3	33.0	1.25	19	23	0.589
11	250	0.33	08.3	31.0	1.24	15	23	0.612
12	150	0.28	22.9	30.0	1.25	16	23	0.282
13	150	0.28	27.2	39.0	1.25	17	20	0.372
14	160	0.28	07.6	39.8	1.24	14	19	0.887
15	150	0.28	08.9	34.0	1.24	17	19	0.726
16	150	0.33	27.4	38.0	1.26	18	19	0.502
17	150	0.28	27.9	38.8	1.25	19	19	0.403
18	150	0.28	27.8	36.2	1.25	20	18	0.422
19	250	0.28	02.4	36.0	1.26	19	18	0.910
20	250	0.33	14.2	24.0	2.35	16	34	0.017
21	250	0.33	17.1	26.0	2.38	17	27	0.123
22	150	0.28	12.5	29.0	2.35	14	37	0.057
23	250	0.33	08.1	32.0	2.38	17	32	0.242
24	250	0.33	09.4	37.0	2.35	18	31	0.254
25	150	0.28	10.2	29.0	2.37	19	34	0.193

Table - 3.11 Dust monitored in Samaleshwari mine for emission in sandstone benches

Sl. No	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate
	d (mm)	P (m/min)	m (%)	s (%)	ρ (gm/cm^3)	σ (MPa)	R	E (g/s)
1	250	0.33	08.2	29.0	2.39	41	32	0.253
2	250	0.33	08.3	31.0	2.35	40	34	0.223
3	150	0.28	11.2	35.0	2.38	41	32	0.311
4	250	0.33	07.9	32.0	2.35	42	35	0.223
5	250	0.33	08.5	30.0	2.37	50	31	0.218
6	150	0.28	10.4	28.5	2.39	46	34	0.173
7	250	0.33	16.1	48.0	2.38	44	34	0.203
8	250	0.33	18.2	42.2	2.37	47	35	0.111
9	150	0.28	15.1	34.5	2.39	49	34	0.123
10	250	0.33	07.9	32.0	1.25	38	18	0.712
11	250	0.33	08.3	30.0	1.26	43	18	0.612
12	150	0.28	10.2	29.0	1.22	49	17	0.688
13	250	0.33	07.9	33.0	1.25	48	27	0.423
14	250	0.33	08.3	31.0	1.24	49	19	0.703
15	150	0.33	08.2	32.0	1.27	42	17	0.911

Table - 3.12 Dust monitored in Samaleshwari mine for concentration in coal benches

Sl. No	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Concentration
	d (m)	T (^{o}c)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (μg/m^3)
1	10	42.3	38.9	3.2	12	20	0.912	525
2	15	42.3	38.9	3.2	12	20	0.712	419
3	20	42.3	38.9	3.1	12	20	0.562	292
4	10	39.0	38.9	3.2	12	20	0.412	201
5	20	39.0	38.9	3.2	12	20	0.222	111
6	40	39.0	40.0	3.2	12	20	0.412	182
7	50	41.0	40.0	3.1	12	20	0.622	271
8	60	41.0	40.0	2.9	12	20	0.572	217
9	70	41.0	40.0	2.9	12	20	0.678	318
10	20	42.0	40.0	2.9	12	20	0.789	426
11	30	42.0	40.0	2.9	12	20	0.612	339
12	06	42.0	38.6	3.1	12	20	0.782	428
13	08	38.0	38.6	3.2	12	20	0.672	328
14	16	38.0	38.6	3.1	12	20	1.002	511
15	24	38.0	38.6	3.1	12	20	0.926	411
16	15	42.0	38.6	3.1	12	20	0.462	271
17	52	42.0	38.9	3.2	12	20	0.673	342
18	10	42.0	38.9	3.1	12	20	0.622	362
19	64	41.0	38.9	3.2	12	20	1.210	562
20	35	41.0	40.1	3.2	12	20	0.617	292
21	29	41.0	40.2	3.1	12	20	0.323	176

Table - 3.13 Dust monitored in Samaleshwari mine for concentration in sandstone benches

Sl. No	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Concentration
	d (m)	T (^{O}c)	RH (%)	u (m/s)	σ_Z (m)	σ_y (m)	E (g/s)	C (μg/m^3)
1	20	41.0	38.6	3.0	12	20	0.667	338
2	45	42.5	40.1	3.0	12	20	0.712	359
3	55	42.5	38.1	3.0	12	20	0.634	339
4	65	42.5	40.1	3.0	12	20	0.923	436
5	75	42.5	40.1	3.0	12	20	0.623	302
6	25	42.5	38.1	3.0	12	20	0.823	426
7	35	42.5	40.1	3.0	12	20	0.611	301
8	05	44.5	40.0	3.0	12	20	0.923	478
9	10	44.5	40.0	3.0	12	20	0.588	311
10	15	44.5	30.4	3.2	12	20	0.603	399
11	20	44.5	40.0	3.2	12	20	0.603	329
12	10	44.5	40.0	3.3	12	20	0.411	271
13	20	44.5	40.0	3.1	12	20	0.473	302
14	40	44.5	37.8	2.9	12	20	0.612	365
15	50	44.5	40.0	2.9	12	20	0.912	467
16	60	44.5	40.0	2.9	12	20	0.588	311
17	70	44.5	40.0	2.9	12	20	0.823	411
18	20	44.5	40.0	2.9	12	20	0.603	342
19	30	44.5	40.0	3.0	12	20	0.411	222

3.4.4 Case study-4

The case study-4 was carried out in Choutapalli limestone mine of My Home Industries Limited, Kodada in Nalgonda District of Telangana State. A view of Choutapalli limestone mine is shown in Fig. 3.16. This mine is situated at a distance of 3km South West of Mellacheruvu village and 3km South East of Choutapalli village. The mine is featured in survey of India Topo sheet no.56 P/13, falling between the Longitude 16^{o} 47″ 51′ to 16^{o} 48″ 52′ and the Latitude falls between 79^{o} 54″ 53′ to 79^{o} 55″ 52′ and is having a total mining lease of 262.247 hectares.

Fig. 3.16A

Fig. 3.16B

Fig. 3.16 Broad view of Choutapalli limestone mine

3.4.4.1 Dust monitoring during drilling activity in Choutapalli limestone mine

The type of reserve available in this mine is high grade (Grey color) limestone. Field investigations were carried out in June-July, 2015. Benching method is adopted to extract the deposit. Blastholes are drilled by Atlas Capco drill having 115mm diameter. Each blasthole is charged with explosives and initiated with detonators. Fragmented material is loaded with the help of shovels into dumpers and transported to in pit crushers for crushing into required size.

Dust monitoring instruments were placed near to drilling operation as shown in Figs. 3.17 and 3.18. These drills were operated at a penetration rate ranging between 0.13m/min and 0.25m/min. Jack hammer drill was also used for drilling for secondary blasting with 32mm diameter. Monitoring of dust dispersion from this drilling operation was also considered for investigations.

Fig. 3.17 Personal dust monitor near drilling activity in limestone benches

Fig. 3.18 Ambient point dust monitor near drilling activity in limestone benches

Some limestone samples were collected from different benches and brought to the laboratory for determining various physico-mechanical properties. Details are given in Table - 3.14. The meteorological parameters were monitored with meteorological station. The meteorological parameters showed variation on a given day and also there was minor variation in wind speed to some extent. The maximum wind speed recorded was 8.6 m/s. The maximum level of temperature and humidity recorded during this period was 37°C and 54.9% respectively, while the minimum was found to be 30°C and 31.2%. Dust dispersion coefficients were determined based on downwind distance with respect to wind velocity from Giffored Pasquills formula. The meteorological parameters and dust concentration values are given in Table - 3.15.

In total, 22 samples were collected from limestone benches for emission, which ranged between 0.027g/s and 0.282g/s. Detailed dust emission values obtained are given in Table - 3.14. Similarly, 39 samples were collected for dust concentration which ranged between 151µg/m^3 and 525µm/m^3. Detailed dust concentration values along with other parameters are given in Table-3.15.

Table - 3.14 Dust emission parameters and dust emission monitored in Choutapalli limestone mine for emission model

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (gm/cm^3)	σc (MPa)	R	E (g/s)
1	115	0.13	08.9	69.0	2.67	59	27	0.199
2	115	0.15	08.6	68.0	2.69	62	25	0.221
3	115	0.15	05.0	59.3	2.69	63	27	0.155
4	032	0.25	05.5	54.0	2.69	59	28	0.121
5	115	0.15	08.3	61.0	2.69	63	27	0.102
6	115	0.15	01.4	54.5	2.63	63	28	0.177
7	032	0.25	02.6	42.0	2.69	62	24	0.117
8	115	0.13	06.3	63.0	2.72	62	27	0.131
9	115	0.16	10.2	69.0	2.71	63	24	0.252
10	115	0.16	07.1	53.0	2.67	63	24	0.138
11	032	0.25	11.4	66.0	2.69	71	25	0.199
12	115	0.15	07.9	54.0	2.52	62	25	0.133
13	115	0.15	05.4	69.0	2.67	77	25	0.265
14	115	0.13	03.1	61.0	2.69	71	24	0.282
15	032	0.25	07.8	64.0	2.69	72	27	0.149
16	115	0.13	02.4	58.0	2.79	63	28	0.112
17	115	0.13	04.2	48.8	2.65	68	25	0.027
18	032	0.25	05.6	56.2	2.63	63	25	0.181
19	115	0.15	02.5	56.0	2.69	74	28	0.123
20	032	0.25	05.6	54.0	2.63	64	27	0.129
21	032	0.25	11.9	24.0	2.72	64	27	0.131
22	032	0.25	06.6	29.0	2.52	66	25	0.121
23	115	0.15	05.1	69.0	2.61	77	25	0.261
24	115	0.13	03.2	61.0	2.69	71	24	0.280

Table - 3.15 Dust influence parameters and dust monitored in Choutapalli limestone mine for concentration model

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration
	D (m)	T (^{o}c)	R_h (%)	U (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (μg/m^3)
1	40	37	32.1	3.7	11.0	18	0.476	229
2	25	34	40.0	4.1	07.5	14	0.602	187
3	30	35	37.2	4.1	07.5	14	0.430	167
4	35	37	32.1	3.7	11.0	18	0.520	192
5	50	35	37.2	4.1	07.5	14	0.723	269
6	60	37	32.1	3.7	07.5	14	0.875	322
7	05	31	48.2	4.0	11.0	18	1.552	510
8	03	31	48.2	4.0	07.5	14	1.552	525
9	100	31	48.2	4.0	07.5	14	1.552	401
10	80	35	37.2	4.1	11.0	18	0.900	319
11	90	37	32.2	1.8	07.5	14	0.887	263
12	80	32	46.0	2.9	07.5	14	0.887	262
13	70	32	46.0	2.9	11.0	18	0.887	268
14	15	32	46.0	2.9	11.0	18	0.847	291
15	05	32	44.0	7.2	07.5	14	1.333	453
16	45	32	44.0	7.2	07.5	14	1.333	501
17	50	34	36.2	8.3	11.0	18	0.529	225
18	08	35	35.0	4.2	07.5	18	0.962	435
19	45	37	34.6	4.3	07.5	14	0.729	311
20	55	36	32.0	4.0	11.0	18	0.599	251
21	25	32	43.6	4.3	07.5	14	0.970	331
22	20	32	43.6	4.3	07.5	14	0.711	257
23	35	32	43.6	4.3	11.0	18	0.589	189
24	10	30	50.1	4.3	07.5	14	0.848	212
25	60	33	46.5	2.9	07.5	14	0.666	171
26	73	33	46.5	2.9	11.0	18	0.663	173
27	82	33	46.5	2.9	11.0	18	0.758	182
28	95	35	43.4	1.4	07.5	14	0.607	129
29	73	35	43.4	1.4	07.5	14	0.996	283
30	60	35	43.4	1.4	11.0	18	0.851	261
31	70	34	44.0	3.4	07.5	14	0.784	251

Table - 3.15 Dust influence parameters and dust monitored in Choutapalli limestone mine for concentration model cont..

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration
	D (m)	T (^{o}c)	R_h (%)	U (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (μg/m^3)
32	55	34	44.0	3.4	07.5	14	0.794	262
33	32	34	44.0	3.4	11.0	18	0.637	214
34	25	31	48.5	8.6	07.5	14	0.827	289
35	40	32	44.9	6.8	07.5	14	0.714	266
36	35	34	40.2	5.8	11.0	18	0.615	262
37	105	30	54.9	1.4	07.5	14	0.967	151
38	95	32	47.5	5.8	07.5	14	0.674	152
39	80	33	42.3	6.1	11.0	18	0.592	156
40	55	36	32.0	4.0	11.0	18	0.599	241
41	25	32	43.6	4.3	07.5	14	0.970	321
42	20	32	43.6	4.3	07.5	14	0.711	237
43	35	32	43.6	4.3	11.0	18	0.589	199
44	10	30	50.1	4.3	07.5	14	0.848	202
45	60	33	46.5	2.9	07.5	14	0.666	161
46	73	33	46.5	2.9	11.0	18	0.663	169
47	82	33	46.5	2.9	11.0	18	0.758	172

3.4.5 Case study-5

Case Study- 5 was carried out in Yenakandla limestone mine, Banaganepalli in Kurnool District of Andhra Pradesh. The Yenakandla limestone mine is meant to cater the limestone requirement of 3.2Mt per annum to the Cement plant. The Mine is bounded by North Latitude 15^{o} 20″ 00′ to 15^{o} 23″ 00′ and East Longitude 78^{o} 08″ 30′ to 78^{o} 12″ 05′ falling under Topo Sheet No.571/3 in Yenakandla village.

3.4.5.1 Dust monitoring during drilling activity in Yenakandla limestone mine

The type of reserve available in this mine is high grade limestone. Field investigations were carried out in the month of December, 2015 to monitor the dust produced during drilling operation. Benching method is adopted to extract limestone. Blastholes of 115mm diameter are drilled and charged with cartridge explosives and initiated with shocktube detonators (Fig.3.20). Fragmented material is loaded using shovels into dumpers and transported to crushing unit.

To determine dust concentration level in the field, initially meteorological data was obtained from meteorological station which was installed in the mine. Vertical dispersion coefficient ($\boldsymbol{\sigma_z}$) and horizontal dispersion coefficient (σ_y) were determined based on downwind distance from the Pasquill-Gifford graphs (Chaulya et al., 1999; Peavy et al., 1985). Other parameters such as moisture content, silt content, density, compressive strength and rebound hardness values of different samples were determined in the laboratory, and the values are given in Table-3.16. Dust monitoring instruments were placed nearer to drilling operation as shown in Figs 3.19 and 3.20. In total, 30 samples were collected from limestone benches for the emission, which ranged between 0.101g/s and 0.471g/s. Detailed dust emission values obtained are given in Table-3.16. Similarly, 30 samples were collected for dust concentrations values which ranged between $201 \mu g/m^3$ to $601 \mu g/m^3$. Monitoring distances varied from 5m to 75m. Detailed dust concentration values along with other parameters are given in Table-3.17.

Table - 3.16 Dust emission parameters and dust emission monitored in Yenakandla limestone mine for emission model

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (gm/cm^3)	σc (MPa)	R	E (g/s)
1	115	0.20	00.5	44.0	2.67	63.7	27	0.115
2	115	0.20	00.5	38.8	2.69	66.7	25	0.101
3	115	0.20	00.5	57.1	2.69	66.7	27	0.284
4	115	0.18	02.0	57.2	2.79	58.8	28	0.186
5	115	0.18	02.0	59.3	2.69	62.5	27	0.229
6	115	0.18	00.6	54.5	2.63	66.7	28	0.169
7	115	0.19	00.6	43.1	2.69	58.8	24	0.152
8	115	0.19	00.9	53.1	2.72	62.5	27	0.174
9	115	0.19	03.0	51.2	2.71	62.5	24	0.211
10	115	0.18	04.0	33.0	2.67	66.7	28	0.249
11	115	0.18	00.2	22.0	2.69	66.7	25	0.348
12	115	0.18	03.0	32.3	2.69	58.8	25	0.371
13	115	0.20	00.3	27.0	2.67	62.5	25	0.347
14	115	0.20	00.8	21.0	2.69	58.8	24	0.353
15	115	0.20	00.9	34.0	2.69	62.5	27	0.471
16	115	0.05	07.9	42.2	2.67	63.0	28	0.147
17	115	0.20	05.6	28.4	2.67	66.7	25	0.335
18	115	0.18	00.9	23.9	2.69	58.8	27	0.263
19	115	0.18	07.8	36.0	2.69	62.5	28	0.292
20	115	0.18	07.0	24.0	2.79	62.5	27	0.144
21	115	0.15	08.3	28.2	2.67	63.0	27	0.141
22	115	0.18	00.5	29.0	2.63	66.7	27	0.319
23	115	0.18	00.4	22.3	2.69	58.8	24	0.328
24	115	0.18	00.6	23.2	2.72	62.5	27	0.252
25	115	0.18	00.5	23.4	2.71	66.7	24	0.327
26	115	0.18	00.8	21.4	2.67	58.8	28	0.253
27	115	0.17	00.9	31.2	2.69	62.5	25	0.383
28	115	0.15	16.9	37.2	2.71	63.0	26	0.118
29	115	0.18	12.5	24.2	2.67	58.8	25	0.141
30	115	0.25	02.4	22.6	2.69	62.5	28	0.328

Table - 3.17 Dust influence parameters and dust monitored in Yenakandla limestone mine for concentration model

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration
	D (m)	T (^{o}c)	R_h (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (μg/m^3)
1	05	23	73	1.94	11.0	18	1.892	601
2	10	23	63	1.94	07.5	14	1.071	227
3	15	23	73	1.94	07.5	14	1.664	421
4	17	29	44	1.94	11.0	18	0.868	272
5	20	29	44	1.94	07.5	14	1.729	521
6	30	29	44	1.94	07.5	14	0.863	208
7	30	29	44	1.94	11.0	18	0.832	244
8	30	31	37	1.94	07.5	14	0.834	222
9	33	31	37	1.94	07.5	14	0.811	220
10	36	31	37	1.94	11.0	18	0.819	297
11	50	31	37	1.94	07.5	14	0.828	261
12	56	33	31	2.50	07.5	14	0.822	255
13	60	33	31	2.50	11.0	18	0.827	243
14	65	33	31	2.50	11.0	18	0.853	294
15	75	34	29	2.50	07.5	14	0.851	250
16	23	34	29	2.50	07.5	14	0.727	341
17	65	31	43	2.20	11.0	18	0.835	201
18	73	31	43	2.20	07.5	14	0.863	226
19	45	31	29	2.20	07.5	14	0.832	283
20	40	31	43	2.20	11.0	18	1.002	367
21	35	33	36	2.20	11.0	18	0.811	302
22	32	33	36	2.20	07.5	14	0.819	321
23	27	33	36	2.20	07.5	14	0.828	344
24	25	33	36	2.20	11.0	18	0.822	344
25	52	34	33	1.10	07.5	14	0.827	327
26	41	34	33	1.10	07.5	14	0.853	263
27	38	34	33	1.10	11.0	18	0.783	299
28	24	23	43	1.94	07.5	14	1.448	410
29	36	23	43	1.94	07.5	14	1.133	328
30	22	23	43	1.94	11.0	18	1.028	290

Fig. 3.19 Broad view of Yenakandla limestone mine

Fig. 3.20 Personal dust monitor near drilling activity in limestone benches

3.4.6 Case study-6

Case Study - 6 was carried out in a granite quarry of M/S Amity Rock Products Private Limited, Chunkappara, Kerala. Broad view of granite quarry is shown in Fig. 3.21. This quarry is situated between latitude 28° 7′ 30′′ and 24° 10′ 55′′ and longitude 52° 4′ 30′′ to 52° 5′ 55′′ East. Granite is fragmented by using drilling and blasting methodology. After the blasting operation, the fragmented muck was being transported to crusher unit using hydraulic shovels and dumpers.

Fig. 3.21 Broad view of granite quarry of M/S Amity Rock Products Private Limited

3.4.6.1 Dust monitoring during drilling activity in granite quarry of M/S Amity Rocks Products Private Limited

The type of granite is Moon white granite. Benching method is adopted to excavate granite from this quarry. Blastholes are drilled with Jack hammer drills of having 34mm and 38mm diameter drill bits (Fig. 3.22).

Fig. 3.22 Personal dust monitor near drilling activity in granite quarry

Field investigations were carried out in the month of February, 2016. The meteorological parameters are such as temperature, relative humidity and wind speed were monitored using meteorological station. As explained in methodology section-3.3, dust monitoring equipments were placed at different distances in downwind direction from drilling activity. Samples were collected carefully and kept in closed containers in order to avoid any moisture variation. Samples were weighed accurately in the laboratory. Vertical dispersion coefficient **(σ_z)** and horizontal dispersion coefficient **(σ_y)** were determined based on downwind distance from the Pasquill-Gifford graphs. Other parameters of moisture content, silt content, density, compressive strength and hardness values were determined in the laboratory, and the values are given in Table - 3.18.

In total, 30 samples were collected for dust emission, which ranged between 0.101g/s and 0.331g/s. Details of dust emission values obtained are given in Table-3.18. Similarly, 30 samples were collected for dust concentration, which ranged between 150µg/m^3 and 643µg/m^3. Dust concentrations values along with other parameters are given in Table-3.19. Monitoring distances varied from 5m to 75m.

Table - 3.18 Dust emission parameters and dust emission monitored in M/S Amity Rock Products Private Limited for emission model in granite benches

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (gm/cm^3)	σc (MPa)	R	E (g/s)
1	38	0.5	0.25	79.4	2.81	178	27	0.299
2	34	0.5	0.16	76.8	2.85	167	27	0.219
3	34	0.5	0.18	79.3	2.62	185	32	0.311
4	34	0.5	0.22	59.4	2.61	167	30	0.218
5	34	0.5	0.50	58.4	2.69	185	26	0.197
6	34	0.5	0.75	62.3	2.91	172	27	0.221
7	34	0.5	0.91	61.3	2.78	178	29	0.331
8	34	0.5	0.35	55.2	2.75	196	28	0.214
9	34	0.5	0.56	56.2	2.61	181	27	0.193
10	34	0.4	1.56	57.2	2.71	181	31	0.266
11	34	0.5	1.45	58.3	2.61	194	33	0.213
12	34	0.5	1.53	59.3	2.77	195	32	0.233
13	38	0.5	0.65	51.2	2.68	189	33	0.318
14	38	0.5	1.63	67.2	2.81	178	31	0.271
15	34	0.5	1.53	52.3	2.69	181	27	0.221
16	38	0.5	2.30	67.4	2.91	178	28	0.224
17	38	0.5	2.40	64.2	2.88	177	27	0.199
18	38	0.5	2.10	67.3	2.75	188	26	0.278
19	38	0.5	2.90	73.4	2.61	179	27	0.327
20	38	0.5	5.30	73.4	2.71	162	29	0.122
21	38	0.4	2.40	73.4	2.61	188	39	0.101
22	38	0.5	2.40	55.0	2.61	182	29	0.121
23	38	0.5	2.50	55.0	2.69	182	28	0.145
24	38	0.5	2.10	55.0	2.61	234	28	0.187
25	38	0.5	0.40	58.0	2.88	217	29	0.166
26	34	0.5	0.70	58.0	2.75	178	29	0.159
27	38	0.4	0.40	58.0	2.61	178	27	0.215
28	38	0.5	1.30	61.0	2.71	188	29	0.193
29	38	0.5	1.30	61.0	2.81	178	30	0.199
30	34	0.5	1.90	61.0	2.65	182	30	0.167

Table - 3.19 Dust influence parameters and dust monitored in M/S Amity Rock Products Private Limited for concentration model in granite benches

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration
	D (m)	T (^{o}c)	R_h (%)	U (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (μg/m^3)
1	05	28.3	64.0	1.72	11.0	18	1.116	304
2	10	28.3	64.0	1.80	07.5	14	1.952	643
3	15	28.3	64.0	1.80	07.5	14	0.919	162
4	17	28.3	64.0	1.72	11.0	18	0.826	126
5	20	30.0	62.0	1.72	07.5	14	0.827	152
6	22	30.0	62.0	1.72	07.5	14	0.829	177
7	23	30.0	62.0	1.72	11.0	18	0.715	119
8	24	30.0	62.0	1.72	07.5	14	0.818	178
9	25	32.0	61.2	1.88	07.5	14	0.923	227
10	27	32.0	61.2	1.88	11.0	18	0.912	201
11	30	32.0	61.2	1.88	07.5	14	0.884	222
12	30	32.0	41.2	1.88	07.5	14	0.632	178
13	30	34.2	59.7	4.33	11.0	18	0.839	201
14	32	34.2	59.7	4.33	11.0	18	0.989	321
15	33	34.2	59.7	4.33	07.5	14	0.799	222
16	35	34.2	59.7	4.33	07.5	14	0.983	277
17	36	27.4	52.5	0.66	11.0	18	0.873	177
18	36	27.4	72.5	0.66	07.5	14	0.978	150
19	28	32.4	42.3	2.66	07.5	14	0.863	335
20	40	27.4	42.3	0.66	11.0	18	1.099	324
21	41	31.6	40.4	2.05	11.0	18	0.985	311
22	45	31.6	40.4	2.05	07.5	14	1.023	341
23	50	31.6	40.4	2.05	07.5	14	0.941	339
24	52	28.7	40.4	2.05	11.0	18	1.074	324
25	56	30.4	40.4	3.86	07.5	14	1.153	326
26	60	30.4	40.4	3.86	07.5	14	0.897	321
27	65	30.4	40.4	3.86	07.5	14	0.987	365
28	65	30.0	53.6	3.86	11.0	18	1.233	376
29	73	30.0	53.6	3.86	07.5	14	1.222	379
30	75	30.0	53.6	3.86	07.5	14	1.231	387

3.4.7 Case study – 7

Case Study- 7 was taken up in a granite quarry of M/S Sadbhav Engineering Private Limited, Kunigal, Karnataka. It is situated between latitude 12^{o} 53′ 42.4 and 12^{o} 13′ 12.4 and longitude 77^{o} 21′ 55.4′′ to 77^{o}′22 14.5′′ East. Typical broad view of granite quarry is shown in Fig. 3.23. In this quarry blastholes were drilled by using wagon drills of 115mm diameter. Later explosives are being used for rock fragmentation. The fragmented material is loaded by shovels in to dumpers and transported in to crushing unit.

Fig. 3.23 Broad view of granite quarry of M/S Sadbhav Engineering Private Limited

3.4.7.1 Dust monitoring during drilling activity in granite quarry of M/S Sadbhav Engineering Private Limited

Field investigations were carried out in March, 2015. Blastholes of 115mm diameters are drilled using wagon drill in granite benches (Fig. 3.24). These drills are operated at a penetration rate ranging between 0.40 and 0.53 m/min.

Different meteorological parameters were monitored using meteorological station. Parameters are such as moisture content, silt content, density, compressive strength and rebound hardness values of different samples were determined in the laboratory.

In total, 24 samples were collected for the emission which ranged between 0.126 and 0.526 g/s. Details of dust emission values are given in the Table-3.20. Similarly, 24 samples were collected for dust concentration which ranged between 124 and 501µg/m^3. Detailed dust concentrations values along other parameters are given in Table-3.21.

Fig. 3.24 Drilling in progress along with dust monitoring

Table - 3.20 Dust emission parameters and dust emission monitored in granite quarry of M/S Sadbhav Engineering Private Limited for emission model

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (gm/cm^3)	σ_c (MPa)	R	E (g/s)
1	115	0.53	2.13	88	2.88	188	39	0.126
2	115	0.53	2.13	88	2.84	177	31	0.326
3	115	0.53	2.13	88	2.56	175	27	0.526
4	115	0.53	2.13	76	2.61	175	28	0.507
5	115	0.53	2.13	76	2.69	175	27	0.407
6	115	0.53	2.13	76	2.81	185	26	0.307
7	115	0.53	2.13	72	2.88	178	27	0.281
8	115	0.53	2.05	72	2.85	186	29	0.221
9	115	0.53	2.05	72	2.71	181	39	0.293
10	115	0.53	2.05	72	2.71	181	31	0.250
11	115	0.53	2.05	65	2.71	184	27	0.189
12	115	0.53	2.05	65	2.77	185	28	0.181
13	115	0.53	3.40	65	2.68	189	27	0.259
14	115	0.40	3.40	65	2.81	188	26	0.214
15	115	0.40	3.40	65	2.79	181	27	0.161
16	115	0.40	3.40	72	2.91	178	29	0.181
17	115	0.40	3.40	72	2.88	177	22	0.228
18	115	0.40	3.40	72	2.85	188	29	0.293
19	115	0.40	3.40	72	2.71	179	28	0.170
20	115	0.40	3.40	72	2.71	172	28	0.152
21	115	0.40	3.40	72	2.71	174	29	0.214
22	115	0.40	3.40	72	2.81	172	29	0.161
23	115	0.40	3.40	72	2.85	178	27	0.181
24	115	0.40	3.40	72	2.71	169	29	0.228

Table - 3.21 Dust influence parameters and dust concentration monitored in granite quarry of M/S Sadbhav Engineering Private Limited for concentration model

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration
	D (m)	T (^{o}c)	R_h (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (µg/m^3)
1	05	32.4	44.2	2.2	7.5	14	0.642	198
2	10	32.4	44.2	2.2	7.5	14	0.542	161
3	15	32.4	44.2	2.2	7.5	14	0.626	173
4	17	33.2	43.0	2.9	7.0	14	0.507	157
5	20	33.2	43.0	2.9	7.5	14	0.507	151
6	22	33.2	43.0	2.9	7.5	14	0.507	151
7	23	34.0	41.4	2.6	7.1	14	0.681	189
8	24	34.0	41.4	2.6	7.5	14	0.421	124
9	25	34.0	41.4	2.6	7.2	14	0.693	177
10	27	35.0	47.0	2.1	7.0	14	1.156	365
11	30	25.0	49.3	2.3	7.0	14	1.289	363
12	30	35.0	49.1	2.1	7.0	14	1.381	482
13	30	28.0	62.1	2.8	7.5	14	1.259	282
14	32	21.0	62.1	2.5	7.5	14	1.214	221
15	33	28.9	42.0	2.3	7.0	14	0.661	134
16	35	30.0	46.0	2.3	7.0	14	1.481	501
17	36	30.0	44.5	2.2	7.5	14	0.628	135
18	36	29.0	50.0	2.7	7.5	14	0.893	221
19	28	28.9	42.8	2.1	7.5	14	1.170	387
20	40	28.8	44.6	2.1	7.5	14	1.152	388
21	41	21.0	62.1	2.5	7.5	14	1.214	211
22	45	28.9	42.0	2.3	7.0	14	0.961	209
23	50	30.0	46.0	2.3	7.0	14	1.033	271
24	52	30.0	44.5	2.2	7.5	14	1.428	395

3.4.8 Case study – 8

Case study- 8 was carried out in a granite quarry of M/S Swamy Ayyappa Crusher Private Limited, Nagamangala, Karnataka. A typical broad view of granite quarry is shown in Fig. 3.25. It is located between latitude 11° 13′ 52′′ and 11° 13′ 15′′ and longitude 78° 11′ 45′′ to 78° 11′ 13.1′′ East. Blastholes were drilled with hand held jack hammer drills of 32mm diameter. Fragmented material is loaded with the help of hydraulic shovel into tippers and transported to crushing unit.

Fig. 3.25A

Fig. 3.25B

Fig. 3.25 Broad view of granite quarry of M/S Swamy Ayyappa Crusher Private Limited

3.4.8.1 Dust monitoring during drilling activity in a granite quarry of M/S Swamy Ayyappa Crusher Private Limited

Blastholes of 32mm diameter were drilled using Jack hammer drill in granite benches. These drills were operated at a penetration rate ranging between 0.15m/min and 0.19m/min. Dust monitoring equipments were placed at different distances of downwind direction from drilling activity. Samples were collected carefully and kept in closed containers in order to avoid any moisture variation. Samples were weighed accurately in the laboratory. The meteorological parameters were monitored by meteorological station. Vertical dispersion coefficient (σ_z) and horizontal dispersion coefficient (σ_y) were determined based on downwind distance from the Pasquill-Gifford graphs. Other parameters are such as moisture content, silt content, density, compressive strength and rebound hardness values of different samples were determined in the laboratory. The values are given in Table-3.22. Blastholes are drilled with Jack hammer drills of having 32mm diameter drill bit and dust monitoring was carried out at different distances (Fig. 3.26).

In total, 23 samples were collected for the emission, which ranged between 0.103g/s and 0.930g/s. Detailed dust emission values obtained are given in Table-3.22.

Similarly, 23 samples were collected for dust concentration ranging between 36µg/m^3 and 478µg/m^3. The monitoring distances varied 05m to 75m. Dust concentrations values along with other parameters are given in Table-3.23.

Fig. 3.26 Personal dust monitor near drilling activity in granite quarry

Table - 3.22 Dust emission parameters and dust emission monitored in a granite quarry of M/S Swamy Ayyappa Crusher Private Limited for emission model

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate
	d (mm)	P (m/min)	m (%)	s (%)	ρ (gm/cm^3)	σ_c (MPa)	R	E (g/s)
1	32	0.15	2.5	69.2	2.88	179	33	0.367
2	32	0.15	2.1	69.2	2.71	165	32	0.412
3	32	0.15	2.1	69.2	2.72	175	30	0.344
4	32	0.15	2.1	69.2	2.71	175	31	0.423
5	32	0.15	2.1	58.2	2.79	175	27	0.323
6	32	0.15	2.1	59.2	2.71	185	38	0.930
7	32	0.15	2.1	51.3	2.78	178	39	0.110
8	32	0.15	2.1	61.3	2.75	176	38	0.123
9	32	0.15	2.1	61.3	2.71	181	39	0.128
10	32	0.15	2.0	61.3	2.71	181	31	0.303
11	32	0.15	2.1	58.3	2.61	175	33	0.203
12	32	0.15	2.0	59.2	2.77	175	32	0.311
13	32	0.15	2.0	59.2	2.68	179	30	0.273
14	32	0.15	2.4	48.2	2.81	175	31	0.152
15	32	0.15	2.4	39.2	2.69	175	27	0.112
16	32	0.19	2.4	47.4	2.71	178	38	0.252
17	32	0.19	2.4	54.2	2.78	181	39	0.143
18	32	0.19	2.6	57.3	2.75	175	39	0.103
19	32	0.19	2.6	39.2	2.61	175	27	0.211
20	32	0.19	2.6	39.2	2.71	179	29	0.117
21	32	0.19	2.6	58.2	2.71	175	39	0.112
22	32	0.19	2.6	39.2	2.71	175	29	0.134
23	32	0.19	3.4	41.3	2.79	181	28	0.123

Table - 3.23 Dust influence parameters and dust monitored in a quarry of M/S Swamy Ayyappa Crusher Private Limited for concentration model

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration
	D (m)	T (°c)	R_h (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (μg/m^3)
1	20	38.0	38.6	3.0	12	20	0.667	312
2	45	38.0	40.1	3.0	12	20	0.712	229
3	55	41.0	38.1	3.0	12	20	0.634	229
4	65	42.0	40.1	3.0	12	20	0.923	436
5	75	42.0	40.1	3.0	12	20	0.623	257
6	25	42.8	38.1	3.0	12	20	0.823	326
7	35	42.8	40.1	3.0	12	20	0.611	301
8	05	44.2	40.0	3.0	12	20	0.923	478
9	10	44.2	33.0	3.0	12	20	0.588	401
10	15	44.2	30.4	3.2	12	20	0.603	399
11	20	41.0	30.4	3.0	12	20	0.603	329
12	10	41.0	30.4	3.3	12	20	0.411	221
13	20	41.0	30.4	3.1	12	20	0.473	302
14	40	38.0	37.8	2.9	12	20	0.212	065
15	50	38.0	37.8	2.9	12	20	0.412	117
16	60	38.0	37.8	2.9	12	20	0.288	092
17	70	38.0	40.0	2.9	12	20	0.223	061
18	20	38.0	40.0	2.9	12	20	0.203	087
19	30	38.0	40.0	3.0	12	20	0.211	081
20	20	37.0	38.6	3.0	12	20	0.467	212
21	45	37.5	40.1	3.0	12	20	0.212	059
22	55	37.5	38.1	3.0	12	20	0.434	159
23	65	37.5	40.1	3.0	12	20	0.223	036

3.5 Modeling Methodology

As part of this research work on development of dust prediction model in surface mines, large amount of data was generated during field investigations. The data included meteorological parameters such as temperature, wind speed and relative humidity of the study area. Also, other parameters such as moisture content, density, rebound hardness number, compressive strength and silt content of the rock samples were determined as per the prescribed procedures in the laboratory. Another important input parameter for modeling is emission inventory of the drilling operation, and it is calculated using modified Pasquill-Gifford formula given by Peavy et al. (1985) for ground level emission rate at the source using the field measured Concentration values. The equation is as follows:

$$C(x, 0) = \frac{(Q*10^6)}{\pi*u*\sigma y*\sigma z} \qquad \text{…..…………Equation (3.6)}$$

where,

$C_{(x,\ 0)}$ = Downwind dust concentration (µg/m^3)

Q = Pollutant emission rate (g/s)

u = Mean wind speed (m/s)

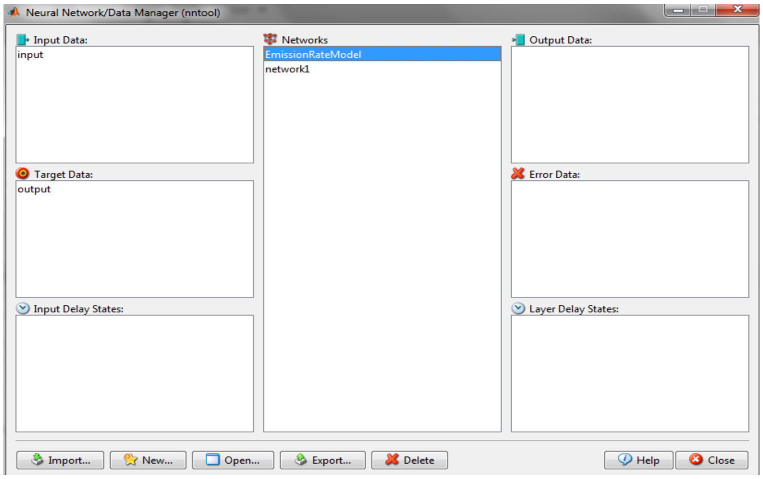
σ_y = Standard deviation of horizontal plume concentration, evaluated in terms of downwind distance x (m) (taken from Pasquill-Gifford diffusion coefficients graph)

σ_z = Standard deviation of vertical plume concentration, evaluated in terms of downwind distance x (m) (taken from Pasquill-Gifford diffusion coefficients graph)

In order to assess the validity of field data for dust prediction models, initially the models were developed and tested using Artificial Neural Networks (ANN) technique in MATLAB R13. As ANN doesn't give mathematical equations, in the second stage empirical models were developed using multiple regression method. Equations were developed using Statistical Package for Social Sciences (SPSS) software V13, which is being used for statistical analysis. The details of ANN method and Multiple Regression Analysis are described below.

3.5.1 Data validation using Artificial Neural Networks (ANN)

Artificial Neural Networks (ANN) is known to be accurate in data prediction based on effectiveness of training of network. However, a mathematical model cannot be developed from ANNs. But, in order to ensure that the data obtained from field investigations is error free, ANN approach was used here. Also predicted values from ANN were compared with field measured values. Fig. 3.27 shows the steps followed in ANN method. The first step in ANN is importing input data from excel sheet into work sheet of MATLAB. Once the input data is imported into, network can be created such as feed forward neural network with back propagation using different types of algorithms, performance function and number of layers etc. (Figs. 3.27A and 3.27B). After creating network; it is to be trained until errors get least value. The Fig.3.27F showing that validating the network is to create a regression plot, which shows the relationship between the outputs of the network and the targets. If the training is perfect, the network outputs and the targets would be exactly equal. The two plots in Fig 3.27F represent the training and validation data. The dashed line in each plot represents the difference between perfect results and outputs results called as targets. The solid line represents the best fit linear regression line between outputs and targets. The R value is an indication of the relationship between the outputs and targets. If R is equal to 1, this indicates that there is an exact linear relationship between outputs and targets. If R is close to zero, then there is no linear relationship between outputs and targets. A snapshot of network training and data simulated is shown in Fig. 3.27.

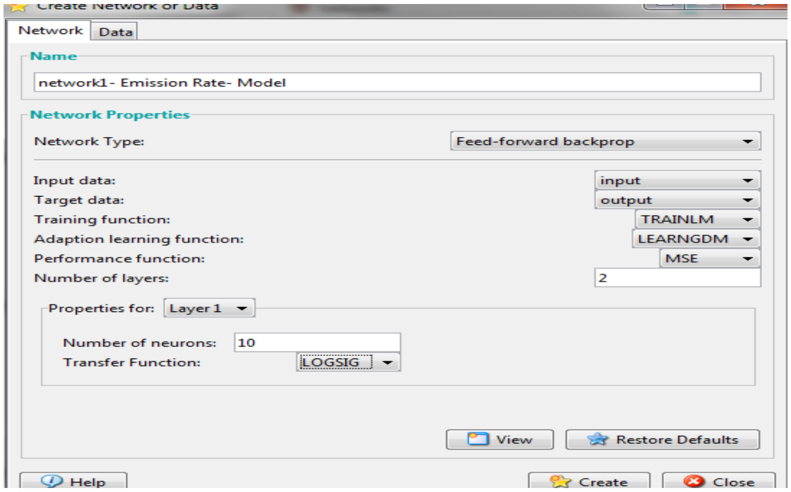


Input Data: input

Networks: EmissionRateModel, network1

Target Data: output

Fig. 3.27A Importing input data into ANN network



Name: network1- Emission Rate- Model

Network Properties

Network Type: Feed-forward backprop

Input data: input

Target data: output

Training function: TRAINLM

Adaption learning function: LEARNGDM

Performance function: MSE

Number of layers: 2

Properties for: Layer 1

Number of neurons: 10

Transfer Function: LOGSIG

Fig. 3.27B Creating a network for emission model

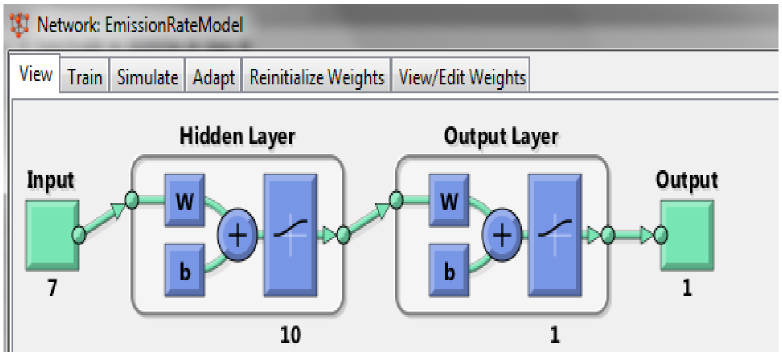
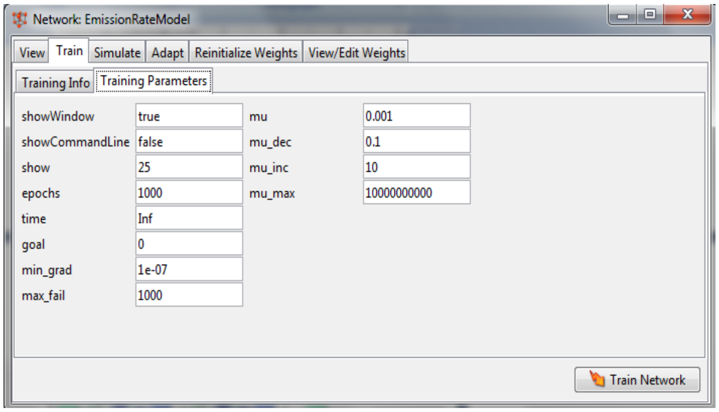
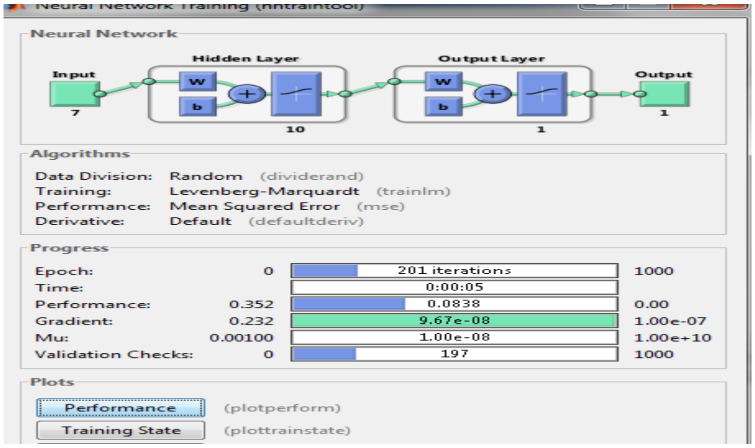


Fig. 3.27C View of neural network architecture



showWindow true
showCommandLine false
show 25
epochs 1000
time Inf
goal 0
min_grad 1e-07
max_fail 1000
mu 0.001
mu_dec 0.1
mu_inc 10
mu_max 10000000000

Fig. 3.27D Selection of training parameters for ANN



Algorithms

Data Division: Random (dividerand)
Training: Levenberg-Marquardt (trainlm)
Performance: Mean Squared Error (mse)
Derivative: Default (defaultderiv)

Progress

Epoch: 0 201 iterations 1000
Time: 0:00:05
Performance: 0.352 0.0838 0.00
Gradient: 0.232 9.67e-08 1.00e-07
Mu: 0.00100 1.00e-08 1.00e+10
Validation Checks: 0 197 1000

(plotperform)
(plottrainstate)

Fig. 3.27E View of network training in ANN

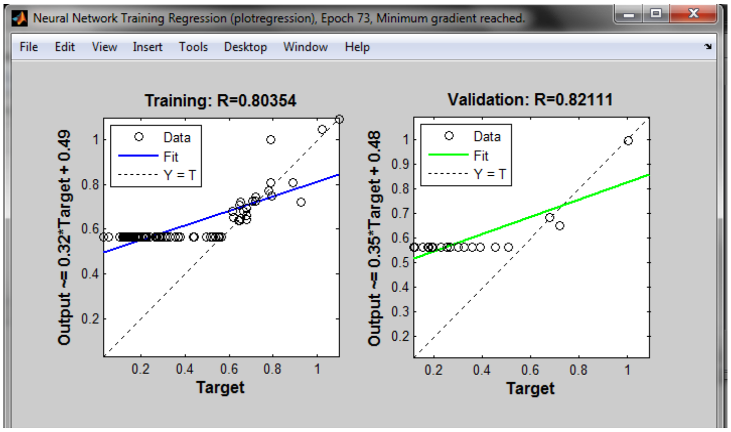
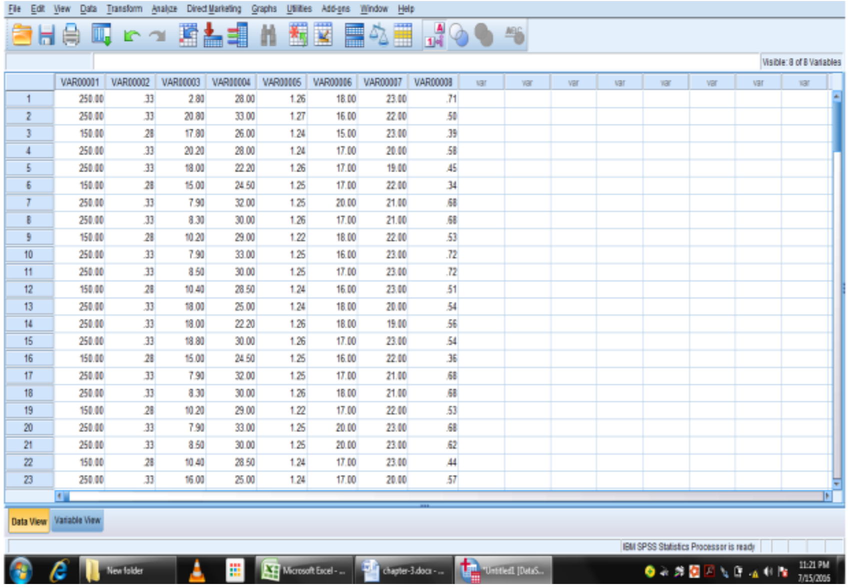

Neural Network Training Regression (plotregression), Epoch 73, Minimum gradient reached.

Fig. 3.27F Validation of output results in ANN

Fig. 3.27 Modelling methodology in ANN method

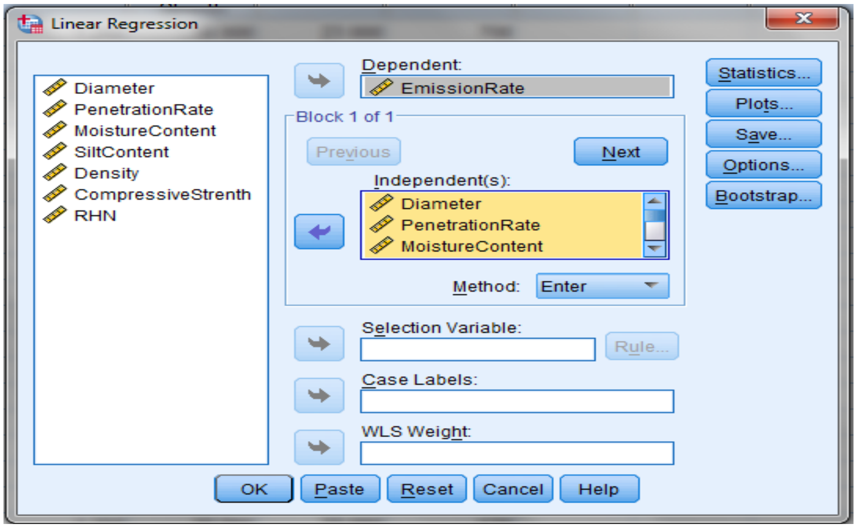
3.5.2 Dust prediction modeling using SPSS

Dust prediction models were developed using SPSS software. SPSS is a Windows based program that can be used to perform statistical analysis. SPSS is capable of handling large amount of data and can perform the analysis covered in the text and much more. In this study SPSS is used for multiple regression analysis. Fig. 3.28 shows the steps followed in SPSS software to develop a mathematical model for dust emission rate and concentration.



	VAR00001	VAR00002	VAR00003	VAR00004	VAR00005	VAR00006	VAR00007	VAR00008
1	250.00	.33	2.80	28.00	1.26	18.00	23.00	.71
2	250.00	.33	20.80	33.00	1.27	16.00	22.00	.50
3	150.00	.28	17.80	26.00	1.24	15.00	23.00	.39
4	250.00	.33	20.20	28.00	1.24	17.00	20.00	.58
5	250.00	.33	18.00	22.20	1.26	17.00	19.00	.45
6	150.00	.28	15.00	24.50	1.25	17.00	22.00	.34
7	250.00	.33	7.90	32.00	1.25	20.00	21.00	.68
8	250.00	.33	8.30	30.00	1.26	17.00	21.00	.68
9	150.00	.28	10.20	29.00	1.22	18.00	22.00	.53
10	250.00	.33	7.90	33.00	1.25	16.00	23.00	.72
11	250.00	.33	8.50	30.00	1.25	17.00	23.00	.72
12	150.00	.28	10.40	28.50	1.24	16.00	23.00	.51
13	250.00	.33	18.00	25.00	1.24	18.00	20.00	.54
14	250.00	.33	18.00	22.20	1.26	18.00	19.00	.56
15	250.00	.33	18.80	30.00	1.26	17.00	23.00	.54
16	150.00	.28	15.00	24.50	1.25	16.00	22.00	.36
17	250.00	.33	7.90	32.00	1.25	17.00	21.00	.68
18	250.00	.33	8.30	30.00	1.26	18.00	21.00	.68
19	150.00	.28	10.20	29.00	1.22	17.00	22.00	.53
20	250.00	.33	7.90	33.00	1.25	20.00	23.00	.68
21	250.00	.33	8.50	30.00	1.25	20.00	23.00	.62
22	150.00	.28	10.40	28.50	1.24	17.00	23.00	.44
23	250.00	.33	16.00	25.00	1.24	17.00	20.00	.57

Fig. 3.28A Importing input data into work sheet of SPSS



Diameter
PenetrationRate
MoistureContent
SiltContent
Density
CompressiveStrenth
RHN

Dependent: EmissionRate

Independent(s):
Diameter
PenetrationRate
MoistureContent

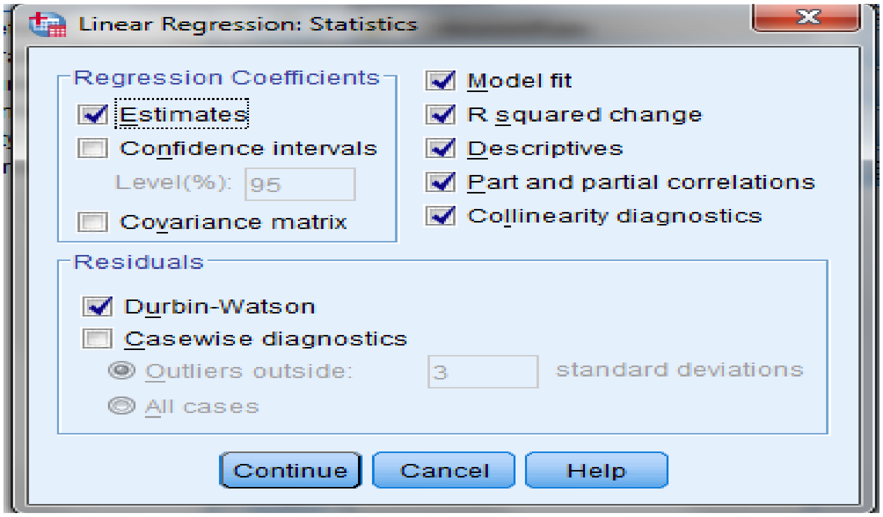
Method: Enter

Selection Variable:

Case Labels:

WLS Weight:

Fig. 3.28B Initial selection of ‘Enter’ method for model development

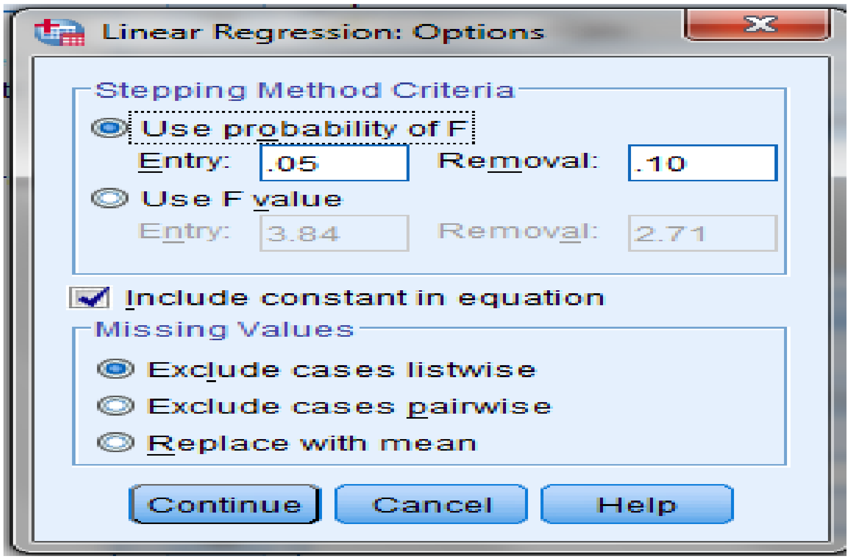


Regression Coefficients
- ☑ Estimates
- ☐ Confidence intervals
  - Level(%): 95
- ☐ Covariance matrix

- ☑ Model fit
- ☑ R squared change
- ☑ Descriptives
- ☑ Part and partial correlations
- ☑ Collinearity diagnostics

Residuals
- ☑ Durbin-Watson
- ☐ Casewise diagnostics
  - ● Outliers outside: 3 standard deviations
  - ○ All cases

Fig. 3.28C Selecting output variable in SPSS



Stepping Method Criteria

● Use probability of F

Entry: .05 Removal: .10

○ Use F value

Entry: 3.84 Removal: 2.71

☑ Include constant in equation

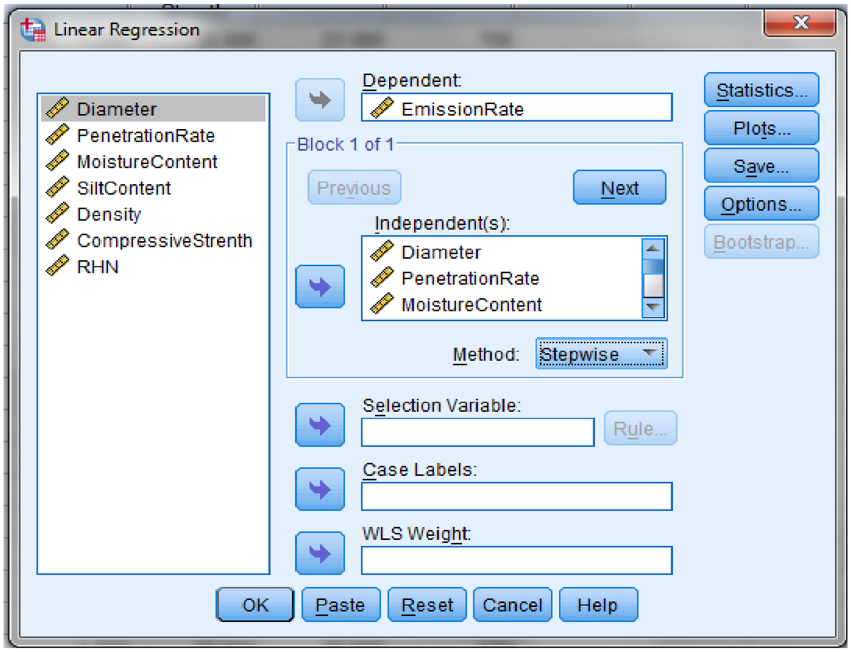
Missing Values

● Exclude cases listwise

○ Exclude cases pairwise

○ Replace with mean

Fig. 3.28D Selection of variables based on 'F' statistics



Diameter

PenetrationRate

MoistureContent

SiltContent

Density

CompressiveStrenth

RHN

Dependent: EmissionRate

Block 1 of 1

Independent(s): Diameter, PenetrationRate, MoistureContent

Method: Stepwise

Selection Variable:

Case Labels:

WLS Weight:

Fig. 3.28E Stepwise method for variable selection in SPSS

Fig. 3.28 Modelling methodologies in SPSS software

Multi-variable linear regression analysis was carried out to predict the dust emission and concentration. A number of statistical parameters or terms associated with multi-variable linear regression analysis were taken into consideration. Predictors (input parameters) used in multiple linear models are moisture content (%), penetration rate (m/min), silt content (%), diameter of drill (mm), rebound hardness number, compressive strength (MPa) and density for emission model. Similarly, for concentration model the parameters are emission rate (g/s), wind speed (m/s), distance from source of dust generation (m), relative humidity (%), temperature (^{o}C). Multiple Regression Analysis (MRA) is a tool that allows examining how multiple independent variables are related to a dependent variable. Performance of the model depends on a large number of factors which act and interact in a complex manner.

The mathematical model for dust concentration with parameters under consideration can be expressed as:

$$Y = f(x_1, x_2, x_3 \ldots) + \epsilon \qquad \text{…………………Equation (3.7)}$$

where,

Y = Response values / output value
x_1, x_2, x_3 = Independent process variables
ϵ = Fitting error.

The model was analyzed through various ways such as R^2 value and Adjusted R^2 value which give the predictability of output value. The coefficient of determination (R^2) represents the status of the best fit line between measured and predicted values. The coefficient can vary between 0 and 1. Higher R^2 value indicates better prediction of the dependent variable. ANOVA analysis is another way to analyze the developed model. It gives various statistical tests of data. The software provides some of the parameters relevant to ANOVA analysis. The parameters are degrees of freedom, mean square, sum of squares, regression, residuals and F- test value. The degrees of freedom provides a measure of quantum of data to reach a certain level of prediction. If the number of degrees of freedom is small, the resulting prediction may be less generalizable because few observations were incorporated in the prediction. ‘F’ test is the ratio of mean square of regression to mean square of residuals. Addition or deletion of variables is performed based on the probability of F value.

In addition to this, the model assessment was carried out using Variable Influence Factor (VIF) method. If VIF factor is more than 10, then that variable is deleted because of collinearity. The collinearity is the expression of the relationship between two independent variables (Montgomery et al., 2003). Input variables are selected based on stepwise regression method.

In order to compare all the reasonable regression models, a stepwise procedure was used as the screening procedure. Then the predictor variable having the absolute smallest ‘t’ value was selected. If the ‘t’ statistic was not significant at the selected level (95% confidence interval), the predictor variable under consideration was removed from the model and the regression analysis was performed using a regression model with remaining predictor variables. If the ‘t’ statistic was significant, the model was selected. The procedure was continued by removing one predictor variable at a time from the model. The screening was stopped when the predictor variable remaining in the model could not be removed further from the system.

3.5.3 Simulation of dust dispersion using ANSYS

Simulation studies were carried out in order to validate the mathematical model developed using SPSS software. A steady state Lagrangian numerical model based Computational Fluid Dynamics (CFD) module of ANSYS V-16.2 software was used to simulate the atmospheric dispersion of PM10 from drilling operation (Fig. 3.29). Atmospheric Boundary Layer (ABL) is one of the important parameters while considering numerical model. Various boundary conditions considered for analysis are atmospheric conditions temperature (38^{o}C), wind velocity (3m/s), drill diameter (115mm), density (2.71gm/cc) and dust emission (1.63g/s).

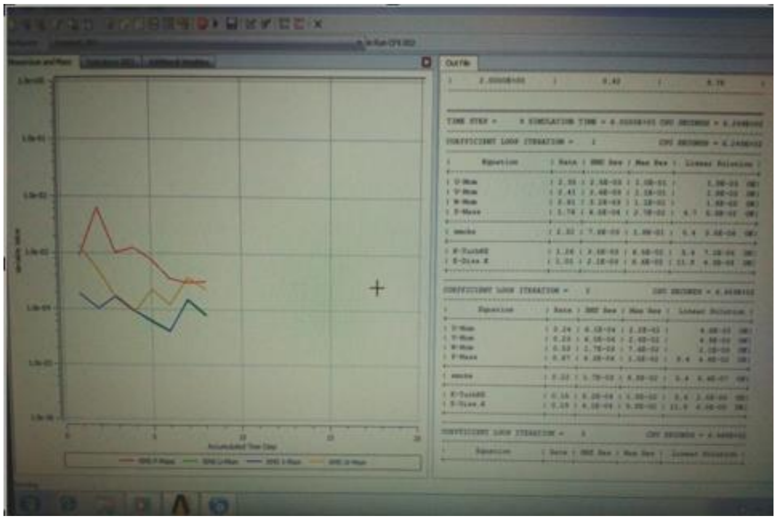


Fig. 3.29A

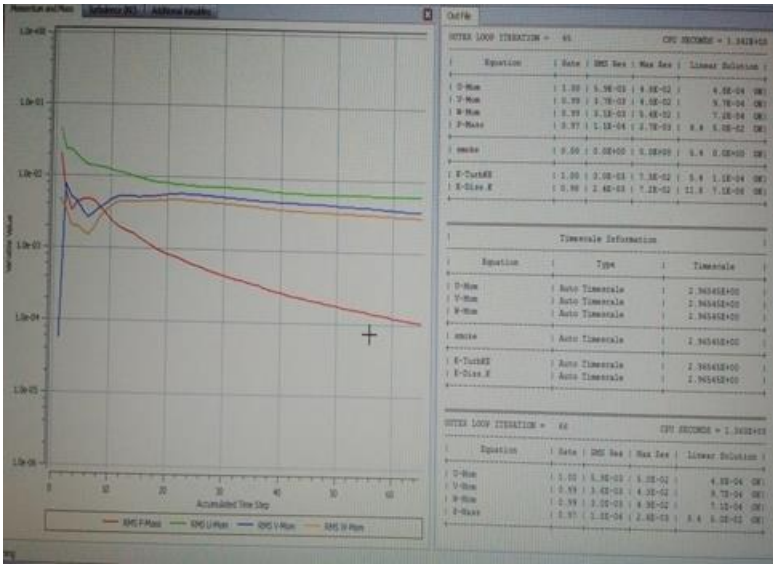


Fig. 3.29B

Fig. 3.29 View of CFD analyses in ANSYS software

CHAPTER - 4

RESULTS AND ANALYSIS

This chapter presents the results obtained from various field investigations carried out and analysis made for modeling of airborne dust emanating from drilling activities in surface mines. Multiple Regression Analysis based statistical modelling approach was used to develop mathematical models for prediction of dust emission and concentration. Developed models were compared with conventional dust prediction models such as Industrial Source Complex Short Term (ISCST3) developed by USEPA. Description of this model is given in Appendix-III.

4.1 Development of Dust Prediction Models

Development of dust prediction models was carried out in two stages. In the first stage, to assess the validity of the field data, Artificial Neural Networks (ANN) approach was used. In the second stage, Multiple Regression method was used to develop mathematical equations for dust emission and dust concentrations from drilling operation in surface mines. Equations were developed using statistical software namely Statistical Package for Social Sciences (SPSS) as described in Chapter-3, section 3.5.2. The input data used for all the methods is given in Appendix-I. Data generated from two different opencast coal mines (Case Study-1 and 2), one limestone mine (Case Study-4), two granite quarries data (Case Study-6 and 7) were used as input data and one coal mine (Case Study-3) data, one limestone mine data (Case Study-5) and one granite quarry (Case Study-8) data were used for validation of developed models given in Appendix-II.

4.1.1 Dust prediction modeling using Artificial Neural Networks

In developing dust prediction models, using ANN, analysis was carried out for different combinations of hidden layers, and network showing least root mean square error was selected. Feed Forward Neural Network with back–propagation algorithm was used to train the network.

In total, 169 sets of data (51 sets of data from coal formation (Tables-3.2 and 3.6), 40 sets of data from sandstone formation (Tables-3.3 and 3.7), 24 sets of data from limestone formation (Table-3.14), and 54 sets of data from granite formation (Tables-3.18 and 3.20), were used for development of emission model. Totally, 184 sets of data (43 sets of data from coal (Tables-3.4 and 3.8), 40 sets of data from sandstone (Tables-3.5 and 3.9), 47 sets of data from limestone (Table-3.15), and 54 sets of data from granite formations (Tables-3.19 and 3.21), were used for development of dust concentration model. Network learning was done by adjusting synaptic weights of multilayer network to known output. Training was stopped when performance of the model on validation data set gave minimum error. Testing data set stimulates actual forecasting of data samples. The Multi-Layer Perceptron (MLP) has fixed architecture, where numbers of hidden neurons are determined by trial and error method. Network was trained using different types of Back-propagation algorithm such as “Trainrp”, “Trainscg”, “Traincgp”, “Trainlm”.

Neural Network Architecture for all emission models is 7:10:1:1, representing 7 input variables, 10 hidden layers, 1 output layer and 1 output variable. Similarly, for concentration model there are 7 input variables, 10 hidden layers, 1 output layer and 1 output variable. The Neural Network Architecture for emission model and concentration models are given in Tables 4.1 and 4.2.

Neural Network Architecture was used for different types of algorithms and their output results showing the time taken for training data, number of epochs and Mean square error for emission and concentration models are given in Tables - 4.1 and 4.2.

An epoch was used to measure number of times all of the training data are used once to update the weights. The numbers of epochs used for different algorithms and time taken to run each algorithm are also given in Tables - 4.1 and 4.2.

Table - 4.1 Performance of different training algorithms for emission values

Training Algorithm	Network Architecture	Number of Epochs	Time taken for Convergence (s)	Mean Square Error
Trainrp	7:10:1:1	03	11	0.036
Trainlm	7:10:1:1	15	05	0.032
Traincgp	7:10:1:1	16	02	0.061
Trainscg	7:10:1:1	05	02	0.052

Table - 4.2 Performance of different training algorithms for concentration values

Training Algorithm	Network Architecture	Number of Epochs	Time taken for Convergence (s)	Mean Square Error
Trainrp	7:10:1:1	33	02	0662.867
Trainlm	7:10:1:1	22	20	0570.141
Trainscg	7:10:1:1	19	03	0947.922
Traincgp	7:10:1:1	17	06	1353.992

The Mean Square Error (MSE) is a measure of how close a fitted line comes to data points. Smaller the MSE value, closer the fit data. The MSE for ‘Trainlm’ (emission model) is 0.032. Similarly, for concentration model smaller MSE for ‘Trainlm’ is 570.14.

The developed models were tested for performance analysis. The performance of the networks was evaluated using Values Account For (VAF), Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). VAF, RMSE and MAPE were computed using the following Equations (4.1, 4.2 and 4.3):

$$\mathrm{VAF} = \left[1 - \frac{\mathrm{var}(y - y')}{\mathrm{var}(y)}\right] \times 100$$

---------------------Equation (4.1)

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y - y')^2}$$

---------------------Equation (4.2)

$$\mathrm{MAPE} = \frac{1}{N}\left[\frac{Ai - Pi}{Ai}\right] \times 100$$

---------------------Equation (4.3)

where,

VAF = Values Account For (%)
RMSE = Root Mean Square Error (%)
MAPE = Mean Absolute Percentage Error (%)
y = Measured values (g/s)
y´ = Predicted values (g/s)
Ai = Actual value or field measured value (g/s)
Pi = Predicted value (g/s)

All the values of VAF, RMSE and MAPE for different algorithms are given in Table-4.3. If the VAF is 100 and RMSE is 0, then the model is considered as excellent or the best fit according to statistical analysis. MAPE is a measure of accuracy in a fitted series value. In statistics it is also used to check the prediction performance of the models. MAPE usually expresses accuracy in percentage.

The ‘Trainlm’ model is statistically more significant for both emission rate and concentration. In case of dust emission, the value of RMSE is 0.019, MAPE value is 89.9 and VAF value is 92.2. Similarly, for concentration the value of RMSE is 6.68, MAPE value is 33 and VAF value is 79.90. ‘Trainlm’ model has higher MAPE value and lower RMSE compared to other models (Table - 4.3). Model ‘Trainlm’ was used for prediction and compared with Multiple Regression Analysis.

Table - 4.3 Performance prediction indices of different training algorithms for emission values and concentration values

Algorithms	**Type of Data**	**Performance Prediction Indices**	**Emission Rate (g/s)**	**Dust Concentration (μg/m^3)**
Traincgp	Training data	VAF	85.300	77.50
		RMSE	00.060	07.11
		MAPE	00.200	30.50
Trainrp	Training data	VAF	39.300	77.40
		RMSE	00.019	06.78
		MAPE	88.500	30.50
Trainscg	Training data	VAF	79.900	75.00
		RMSE	00.020	07.47
		MAPE	87.900	31.00
Trainlm	Training data	VAF	92.200	79.90
		RMSE	00.019	06.68
		MAPE	89.900	33.00

After analyzing the developed model from ANN method using three statistical parameters namely VAF, MSE and MAPE, to further validate the models, predicted values were compared with field measured values. Figs. 4.1 and 4.2 show the correlation between actual field measured values with predicted values of ANN in case of emission rate and concentration. The values used for comparing ANN predicted and field measured values for dust emission and concentrations are given in Appendix-II.

The best fit of the model was assessed using the R^2 value. The R^2 value obtained for emission model is 0.81 and for concentration model it is 0.80, which shows very good correlation.

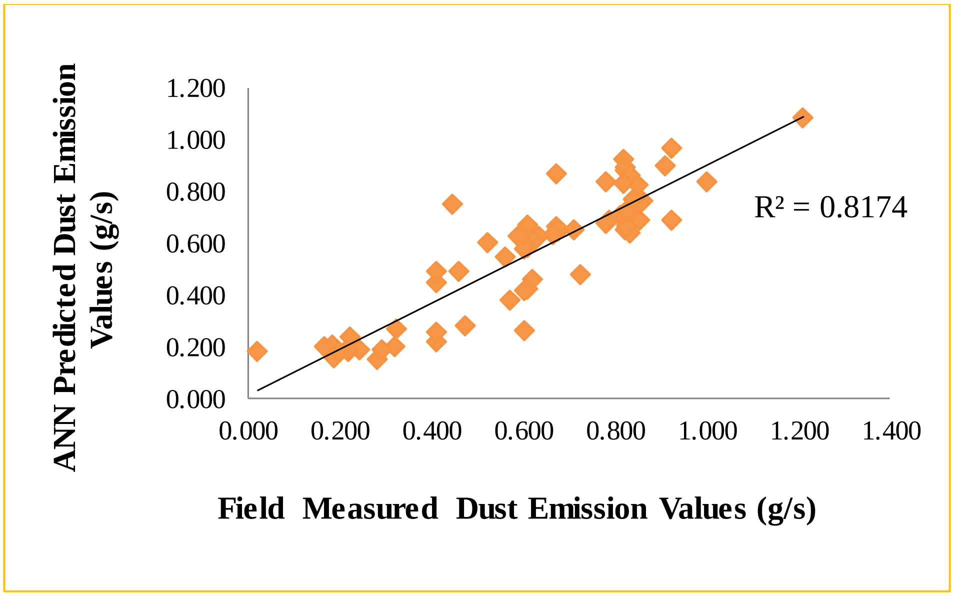


Fig. 4.1 ANN predicted emission values Vs. field measured dust emission values

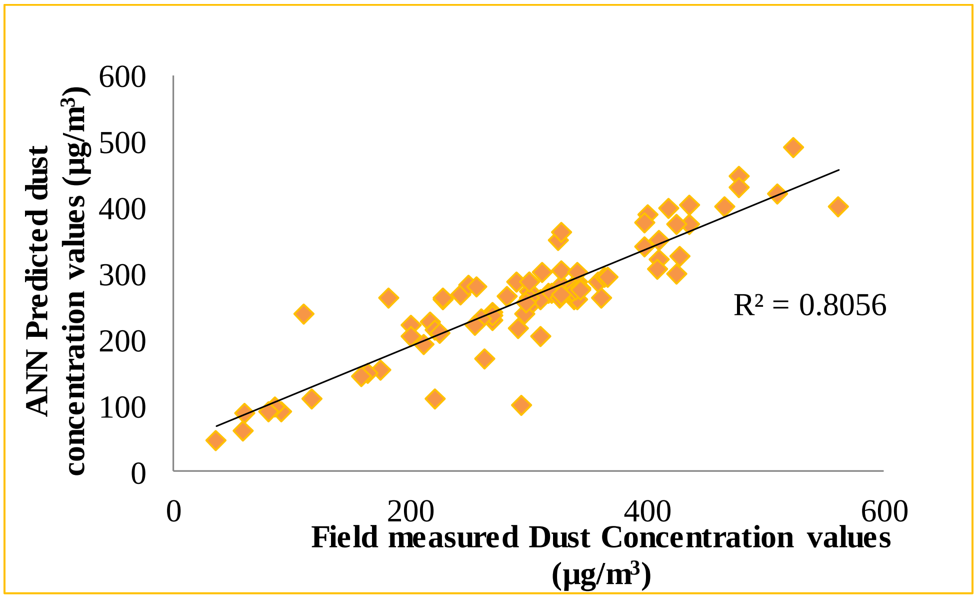


Fig. 4.2 ANN predicted concentrations Vs. field measured dust concentration values

4.1.2 Dust prediction modeling using Multiple Regression Analysis

Though ANN model analysis showed that the field data is error free, it cannot give any mathematical equation. So, in order to develop a mathematical model, multiple regression analysis was used for the same data.

Multiple linear regression models were developed using total 169 sets of data for emission model and 184 sets of data for concentration model from different rock formations. The models were developed using SPSS software version 13.0, for emission of PM10 and concentration of PM10 from drilling operation in surface mines.

The variables considered for emission model development are drill diameter, moisture content, penetration rate, silt content, rebound hardness number, compressive strength and density of rock.

In order to assess the influence of input parameters on output, stepwise regression was used. The criteria for stepwise regression method were: probability of ‘F’ to enter less than 0.05 and probability of F to remove more than 100. The parameter not influencing the output was deleted from the model and parameter that influenced the output was included in the model. Only one parameter was tested each time. All variables included in the model are statistically more significant because of their probability of P value is less than 0.05. So, the developed model is:

$$\mathbf{E_d = 0.754 - 0.001d - 0.019m + 1.252P + 0.011S - 0.021R - 0.003\sigma c - 0.0265\rho}$$

----------Equation (4.4)

where,

E_d = Emission from drilling (g/s)
m = Moisture content (%)
P = Penetration rate (m/min)

S = Silt content (%)

d = Diameter of drill (mm)

R = Rebound hardness number

σc = Compressive strength (MPa)

ρ = Density of rock (g/cc)

Emission model summary is given in Table - 4.4. It can be stated that from R^2 and adjusted R^2, value that the developed model gives more than 82 % satisfactory results with a standard error of 11 %. Similarly, F test carried out using ANOVA **(**Analysis of variance**)** analysis has also resulted in better validation of the model (Table- 4.5). The ANOVA for the emission model indicated that observed value of F was 131.161 and critical value of F was 98.2, indicating that the observed values are more than critical value. So, the developed model is more significant. Detailed description of the parameters listed in Table - 4.5 were given in Chapter-3 in section 3.5.2.

Table - 4.4 Model summary for estimation of dust emission rate

Model	**R**	**R^2**	**Adjusted R^2**	**Std. Error of the Estimate**
1	0.907	0.823	0.815	0.11

Table - 4.5 Analysis of variance (ANOVA) for estimation of dust emission rate

Model	**Activity**	**Sum of Squares**	**Degree of Freedom**	**Mean Square**	**F- test Value**	**Significance (P-Value)**
1	Regression	7.868	6	1.311	131.161	0.000
	Residual	1.696	168	0.010	---	---
	Total	9.564	174	---	---	---

Coefficients of emission model are given in Table - 4.6. Coefficients of parameters determines the relationship between input variables and output variable. The derived regression coefficients are neither zero nor greater than standard error. Variables with zero coefficients or coefficients less than their standard error should not be included in the equations. Variables in

Table - 4.6 are more significant because their probability of 'P' value is less than 0.05. The regression coefficients (B) of predictors are also statistically more significant. If 't' value does not exceed a specified significance level, the variable will not be allowed to enter into the model. The 't' values for a significance level of 95% with 131 degrees of freedom is in Table - 4.6 are more significant because all values of 'P' are less than 0.05.

In addition to this, model assessment has been carried out using Variable Influence Factor (VIF) method. If VIF factor is more than 10, then that variable is deleted because of collinearity. The collinearity is the expression of the relationship between two independent variables. The derived regression coefficients are neither zero nor more than the standard error.

Also, to assess the best performance of the model, the residuals should follow the normal distribution with zero mean. Fig. 4.3 shows the histogram of dependent variables of emission values (Residuals). The residuals analysis shows that the residuals are distributed normally with zero mean.

Table - 4.6 Coefficients of emission model for estimation of dust emission rate

Parameters	Regression Coefficients		T-test	Sig.(P)	VIF
	B	Std. Error			
Constant	0.754	0.100	08.58	0.00	---
Diameter	0.001	0.000	07.73	0.00	4.01
Penetration	1.252	0.264	15.86	0.00	3.53
Moisture content	-0.019	0.003	07.85	0.00	1.89
Silt content	0.011	0.002	08.84	0.00	1.48
Compressive strength	-0.003	0.000	17.32	0.00	3.50
Rebound hardness number	-0.021	0.002	07.74	0.00	1.45
Density of rock	-0.026	0.009	02.02	0.04	3.30

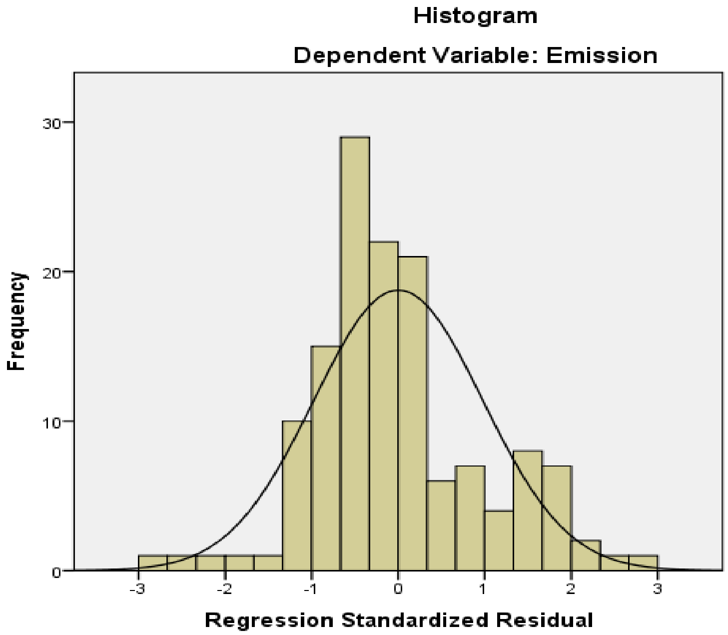


Fig. 4.3 Histogram of dependent variables of emission values

In the second step, total 184 sets of data were used to develop dust concentration model. The variables considered to develop the dust concentration model are Emission rate from drilling operation, Wind speed, Distance between dust source and monitoring point, Relative humidity, Temperature, Vertical dispersion coefficient and Horizontal dispersion coefficient. The following equation 4.5 is developed to predict dust concentration from drilling operation using software generated coefficients.

$$\mathbf{C_d = -279.806 + 410.464Ed - 0.854D + 11.968u + 10.057T - 3.28Rh} \text{ --------Equation (4.5)}$$

where,

C_d = Concentration from drilling ($\mu g/m^3$)

E_d = Emission from drilling (g/s)

u = Wind speed (m/s)

D = Distance between dust source and monitoring point (m)

Rh = Relative humidity (%)

T = Temperature (^oC)

Similar to the emission rate, R^2 and adjusted R^2, standard error values for concentration model are given in Table - 4.7. Prediction model resulted in 81 % satisfactory results with a standard error of 18.9 %. The ANOVA analysis for the concentration model indicated that observed value of F-test was 131.6 and critical value of F- test was 78.2. As observed value is more than critical value, the developed model is more significant. The ANOVA analysis values are given in Table - 4.8. Variables of coefficient values in Table - 4.9 are more than their standard error. Vertical dispersion coefficient and Horizontal dispersion coefficient parameters are excluded from model, because their coefficient values are more than the standard error. Also according to ‘t’ test, those variables ‘P’ value is more than 0.1.

Table - 4.7 Model summary for estimation of dust concentration

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
2	0.901	0.812	0.803	18.9

Table - 4.8 Analysis of variance (ANOVA) for estimation of dust concentration

Model	Activity	Sum of Squares	Degree of Freedom	Mean Square	F- test Value	Significance (P-Value)
2	Regression	1056862.03	006	176143.67	131.6	0.00
	Residual	0244776.51	183	001337.57	---	---
	Total	1301638.54	189	---	---	---

Variable Coefficients and VIF values obtained are given in Table - 4.9. All regression coefficients of predictors are statistically more significant because probability of ‘P’ values for all variables is less than 0.05 according to‘t’ test. VAF values for all variables are less than 10, indicating no multi collinearity. Also, to assess the best performance of the model, the residuals should follow the normal distribution with zero mean. Fig. 4.4 shows, the histogram of dependent variables of concentration values (Residuals). The residual analysis shows that the residuals are distributed normally with zero mean.

Table - 4.9 Model coefficients for estimation of dust concentration

Parameters	Standardized Coefficients		T-test	Sig.(P)	VIF
	B	Std. Error			
Constant	-279.80	88.61	03.15	0.00	---
Distance	-000.85	00.18	04.60	0.00	1.14
Emission	410.46	24.10	17.03	0.00	1.24
Wind speed	011.96	03.41	03.50	0.00	1.16
Temperature	010.05	01.84	05.46	0.00	2.09
Relative humidity	-003.28	00.65	04.98	0.00	2.34

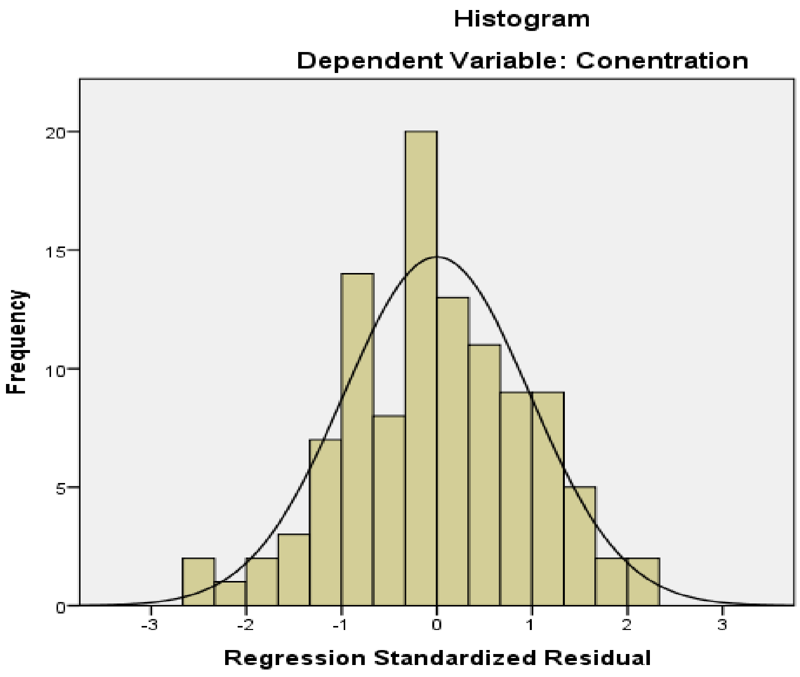


Fig. 4.4 Histogram of dependent variables of concentration values

After validating the developed model through various statistical methods, for further validation, plots were drawn between actual field measured values with predicted values for emission rate and concentration. The values used for comparing SPSS predicted and field measured values for dust emission and concentrations are given in Appendix-1.

The regression coefficient (R^2) values are 0.82 and 0.88 respectively, which showed good correlation indicating that the developed models are giving better prediction (Figs. 4.5 and 4.6).

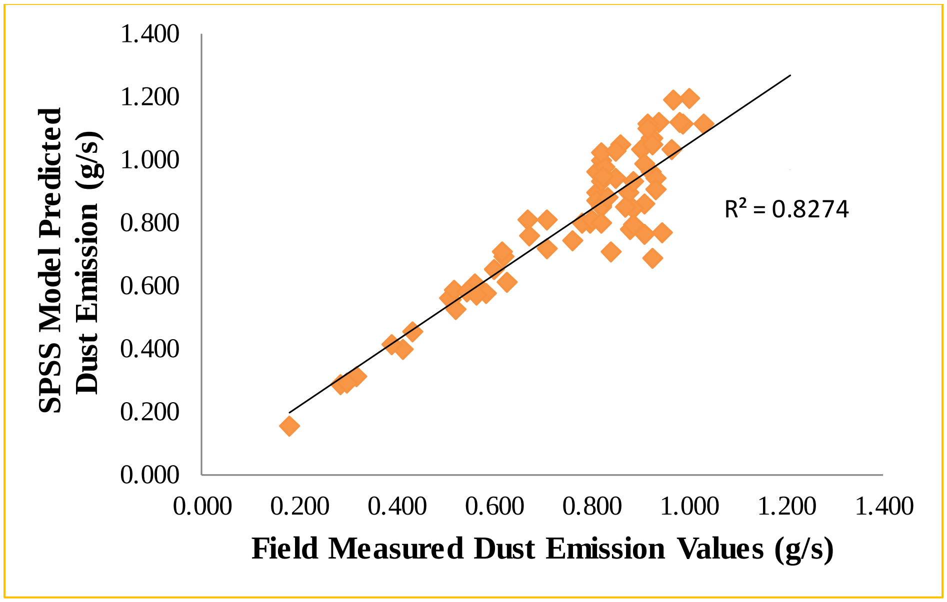


Fig. 4.5 SPSS model predicted emission values Vs. field measured emission values

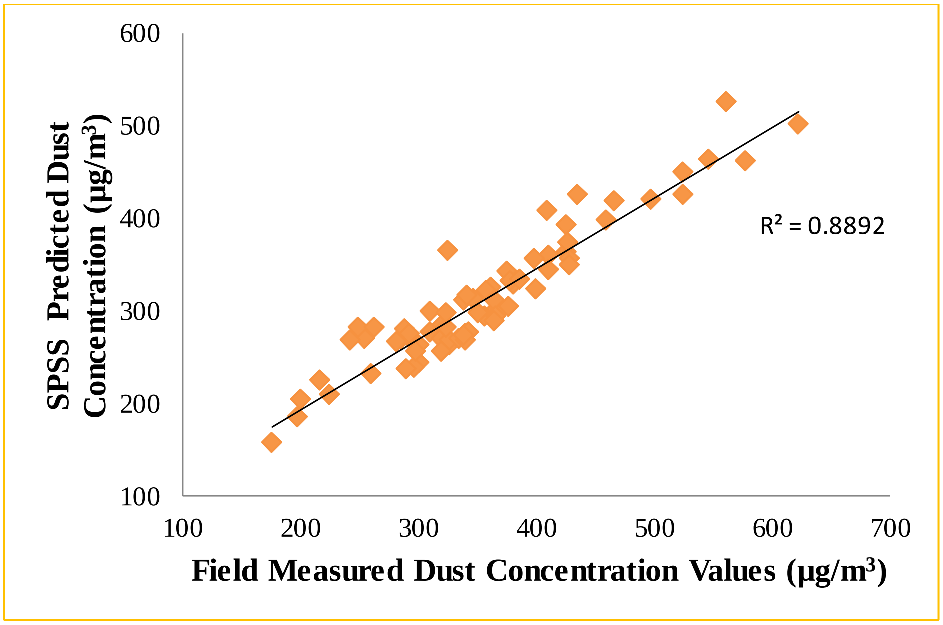


Fig. 4.6 SPSS predicted dust concentration values Vs. field measured dust concentration values

4.2 Simulation of Dust Dispersion

There are various computer numerical models available for simulation studies to solve many engineering problems. A steady state Lagrangian numerical model based Computer Fluid Dynamic (CFD) module of ANSYS V-16.2 software was used to simulate the atmospheric dispersion of PM10 from drilling operation. In CFD, the Eulerian principles were used for airflow modeling.

Atmospheric boundary layer (ABL) is one of the important parameters while considering numerical model. The ABL defines the boundary conditions used in model. Various boundary conditions considered to predict dust concentration from drilling operation are wind velocity, atmospheric conditions, drill diameter and dust emission. The details of boundary conditions considered in the model are given in Table - 4.10. The first step of analysis in ANSYS is creating atmospheric model by considering some of the parameters such as drill diameter, dimensions of the model (500 x 500m is considered in this study) (Fig. 4.7A). The second step of analysis is meshing the entire model as shown in Fig. 4.7B. Boundary conditions are the most important parameters to be considered in the analysis (Fig. 4.7C).

Table - 4.10 Boundary condition values, field measured values used in ANSYS

	THE BOUNDARY CONDITION PARAMETERS					
Boundary Conditions	**Wind Velocity**	**Drill Diameter**	**Temperature**	**Density**	**Dust Emission**	**Compressive Strength**
Units	**(m/s)**	**(mm)**	**(T°c)**	**(g/cm^3)**	**(g/s)**	**(MPa)**
1	3	115	38	2.71	1.63	181

Fig. 4.7 shows, the dispersion of dust particle upto a distance of 100m. The predicted values of dust concentration from ANSYS are given in Table - 4.11. The predicted values were compared to field measured as well as SPSS model predicted values. The percentage of prediction error was up to 34%, whereas the SPSS model predicted with error of 20% from field measure values.

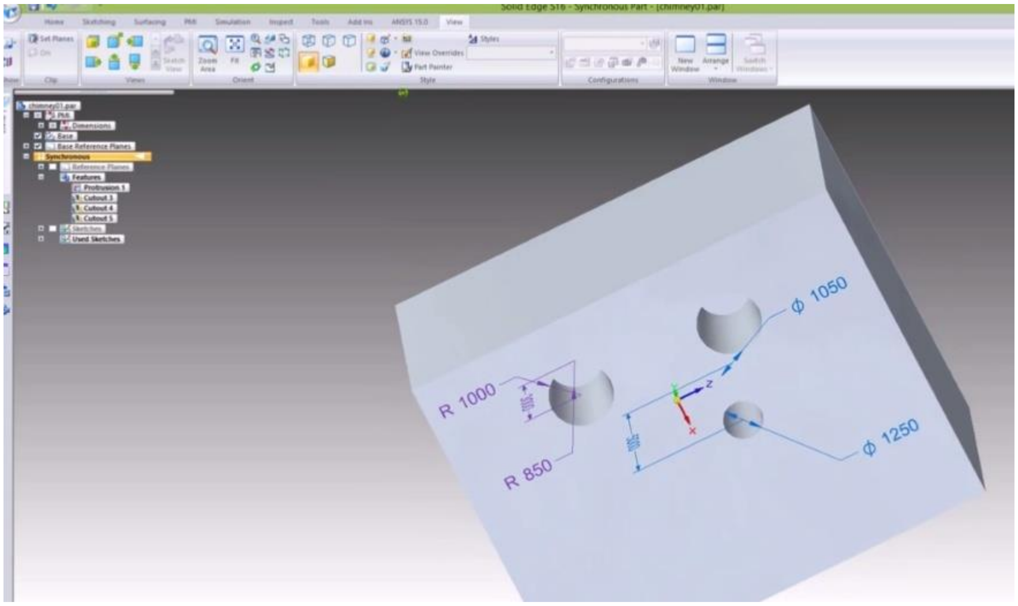


Fig. 4.7A Creating atmospheric model in ANSYS using solid edge

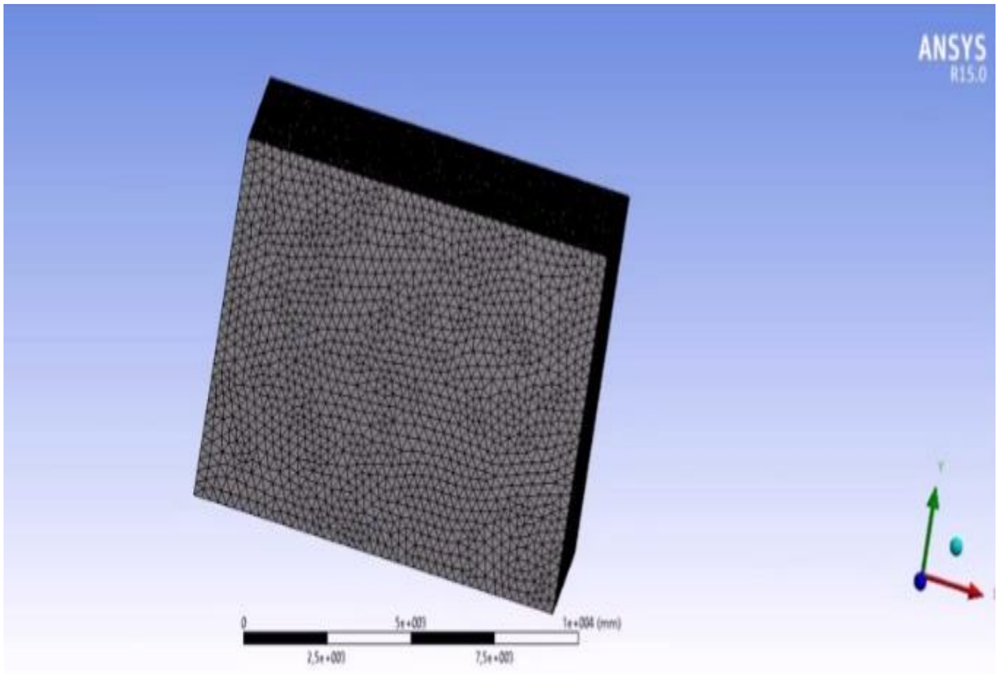


Fig. 4.7B Meshing for atmospheric model

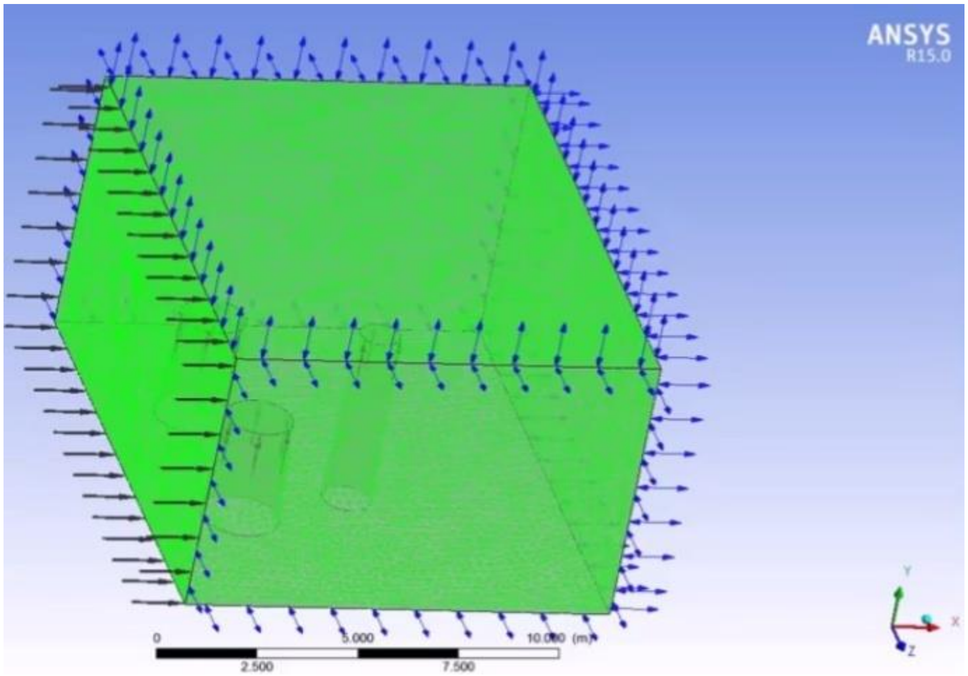


Fig. 4.7C Boundary conditions given to atmospheric model in ANSYS

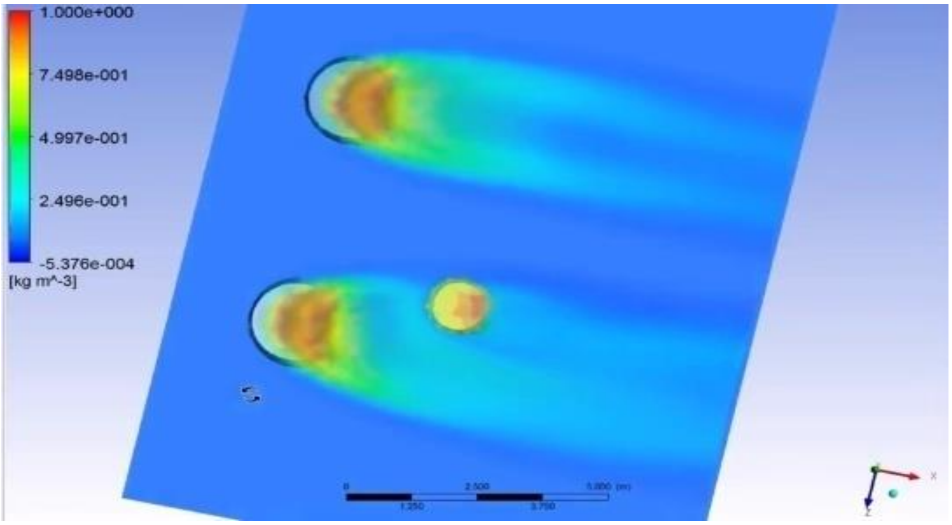


Fig. 4.7 CFD simulation of dust dispersion from drilling operation

Table - 4.11 PM10 concentration values from CFD analysis along with SPSS predicted values

Distances (m)	Field Measured Concentration (µg/m^3)	SPSS Predicted Values (µg/m^3)	% of Error between Field Measured and SPSS Predicted	Predicted Concentration Values by ANSYS (µg/m^3)	% of Error between Field Measured and ANSYS Predicted
05	191	156.6	18.0	146.2	23.5
10	155	125.6	19.0	154.2	00.5
20	144	117.1	18.7	194.1	34.8
25	141	122.2	13.3	188.0	33.3
35	117	098.8	15.6	123.3	05.4
45	111	097.4	12.3	121.2	09.2
60	104	085.0	18.3	131.6	26.5
65	089	084.4	05.2	102.4	15.1
65	085	083.0	02.4	110.8	30.4
70	085	082.8	02.6	099.2	16.7
75	082	081.2	01.0	087.8	07.1

4.3 Influence of Different Parameters on Dust Emission Rate

The dust emission depends upon various parameters such as density, compressive strength, moisture content present in drill cuttings, penetration rate and drill diameter. Influence of various parameters on emission rate was assessed using field emission rate and predicted values.

4.3.1 Influence of compressive strength on emission rate

In order to assess the influence of compressive strength on emission rate, 150mm drill diameter values were considered in coal and sandstone formations. Generally, high compressive strength of rock leads to less penetration and causes less dust emission (Kahraman et al., 2003). Plot between field measured emission values, model predicted values with respective to compressive strength is shown in Fig. 4.8. It was observed that, with increase in compressive strength, the emission rate decreased linearly for coal and sandstone formations. The values used for analysis are given in Table - 4.12.

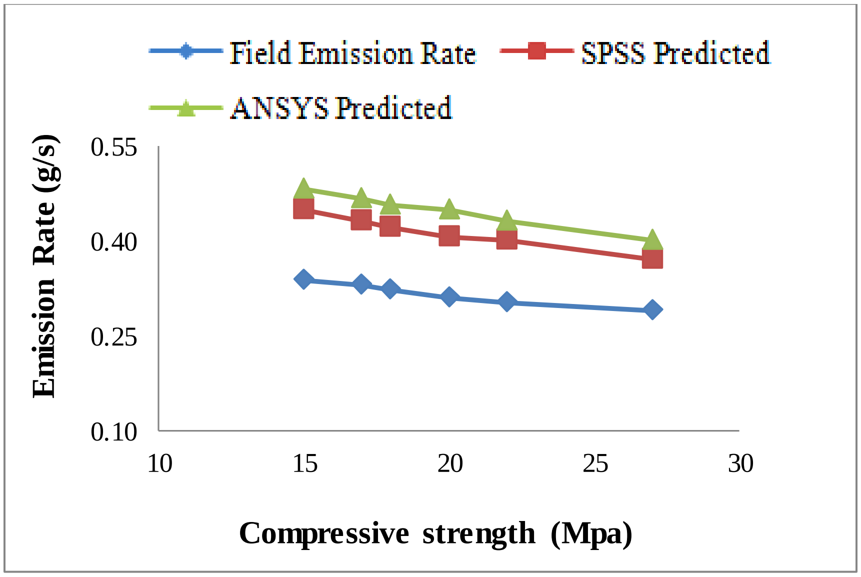


Fig. 4.8 Influence of compressive strength on dust emission rate

Table - 4.12 Data used for comparison of dust emission rate Vs. compressive strength

Sl. No.	Compressive Strength	Field Emission Rate	SPSS Predicted Values	ANSYS Predicted Values
	(MPa)	(g/s)	(g/s)	(g/s)
1	15	0.339	0.449	0.484
2	17	0.330	0.432	0.468
3	18	0.323	0.422	0.457
4	20	0.311	0.408	0.449
5	22	0.302	0.401	0.431
6	27	0.291	0.372	0.401

4.3.2 Influence of drill penetration rate on emission rate

Penetration rate values were considered directly from the field investigations. Penetration rate is the most influencing parameter for dust emission. To study the influence of penetration rate on emission rate, the penetration rate was taken at drill diameter of 115mm in limestone benches. The plot drawn between emission rate and penetration rate is shown in Fig. 4.9. It was observed that, with increase in penetration rate, the emission rate increases linearly. The trend is almost same for field measured, SPSS predicted and ANSYS predicted values. The values used for analysis are given in Table - 4.13.

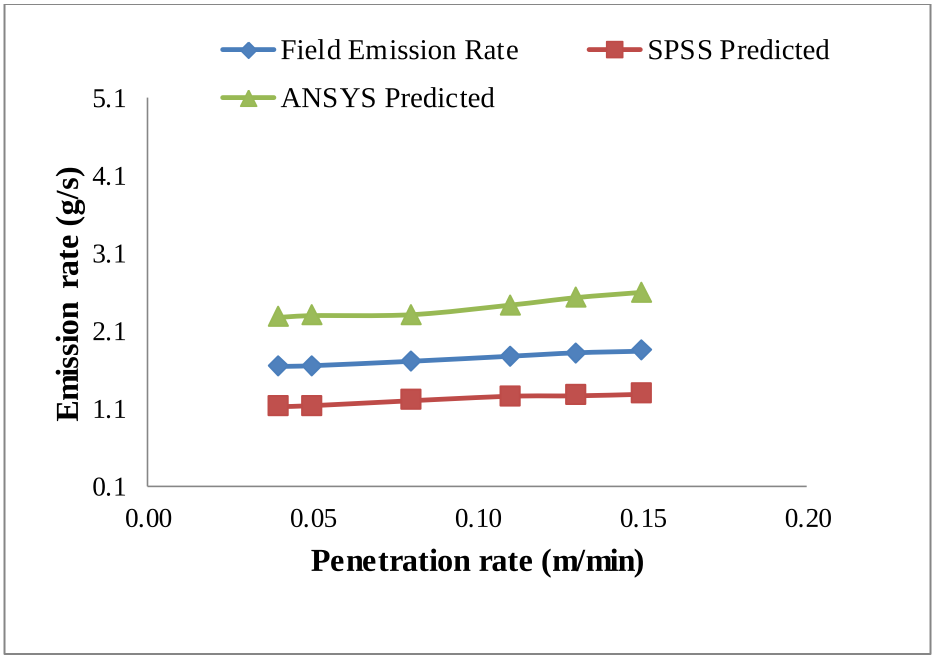


Fig. 4.9 Influence of penetration rate on dust emission rate

Table - 4.13 Data used for comparison of dust emission rate Vs. penetration rate

Sl. No.	Penetration Rate	Field Emission Rate	SPSS Predicted values	ANSYS Predicted values
	(m/min)	(g/s)	(g/s)	(g/s)
1	0.15	1.842	1.286	2.600
2	0.13	1.821	1.267	2.532
3	0.11	1.777	1.261	2.435
4	0.08	1.712	1.204	2.312
5	0.05	1.655	1.140	2.300
6	0.04	1.645	1.128	2.278

4.3.3 Influence of moisture content on emission rate

In order to assess the influence of moisture content on emission rate, moisture content values of sandstone drill cuttings were considered. Moisture content has restraining nature in dust generation and may vary from season to season (Roy et al., 2011).

For this analysis, the field monitoring data from sandstone (PKOC-II) benches during summer and rainy season was considered (Table - 3.14). The plot drawn between emission rate and moisture content is shown in Fig.4.10. With increase in moisture content present in drill cuttings the emission rate decrease linearly, and this could be due to the fact that wet dust tries to settle down quickly due to increased density. The values used for analysis are given in Table - 4.14.

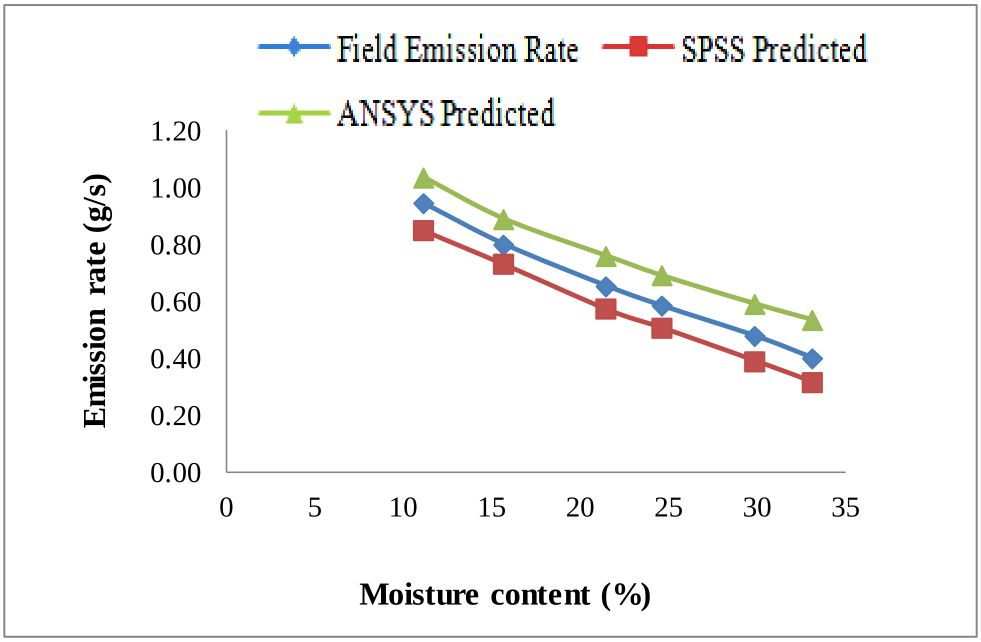


Fig. 4.10 Influence of moisture content on dust emission rate

Table - 4.14 Data used for comparison of dust emission rate Vs. moistute content

Sl. No.	Moisture Content	Field Emission Rate	SPSS Predicted values	ANSYS Predicted values
	(%)	(g/s)	(g/s)	(g/s)
1	11.25	0.941	0.844	1.032
2	15.75	0.799	0.727	0.888
3	21.56	0.652	0.570	0.758
4	24.73	0.582	0.504	0.688
5	29.99	0.476	0.409	0.589
6	33.22	0.339	0.335	0.533

4.3.4 Influence of density on emission rate

To study the influence of density on emission rate, the density value was taken for coal, sandstone, limestone and granite formations. In general, higher density results in lesser penetration rate, and causes lesser dust emission (Kahraman et al., 2003). The plot drawn between field measured values and predicted emission values is shown in Fig. 4.11. It was observed that, with increase in density, the emission rate decreased linearly. The values used for analysis are given in Table - 4.15.

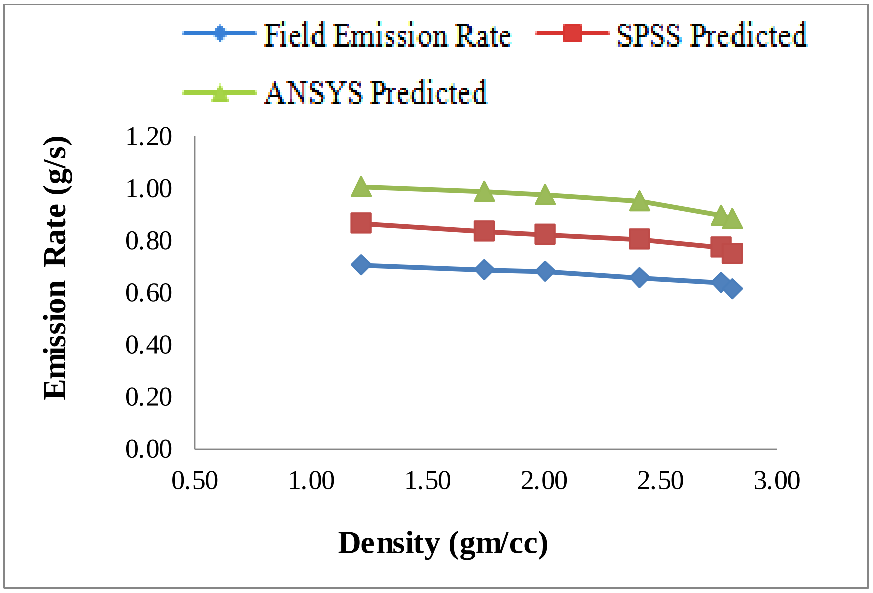


Fig. 4.11 Influence of density on dust emission rate

Table - 4.15 Data used for comparison of dust emission rate Vs. density

Sl. No.	Density	Field Emission Rate	SPSS Predicted values	ANSYS Predicted values
	(gm/cm^3)	(g/s)	(g/s)	(g/s)
1	1.22	0.705	0.862	1.007
2	1.75	0.685	0.833	0.987
3	1.91	0.681	0.822	0.976
4	2.42	0.655	0.800	0.951
5	2.77	0.635	0.773	0.897
6	2.82	0.611	0.745	0.884

4.4 Influence of Different Factors on Dust Concentration

Some of the dispersion parameters such as wind speed and relative humidity play a major role on dust dispersion of drilling fugitive dust. Influence of various parameters on concentration was assessed using field measured concentration particles and predicted values.

4.4.1 Influence of relative humidity on dust dispersion

Moisture content present in the atmosphere varies from one season to another season. Generally, in rainy season moisture content present in the atmosphere is more compared to other seasons. More moisture content present in atmosphere leads to less dust dispersion because particles get higher become denser and settle down at shorter distances. The values are compared between concentration and relative humidity from which it can be concluded that increased relative humidity decreases dust dispersion in atmosphere (Fig. 4.12). The values used for this analysis are given in Table - 4.16 and the data belongs to Case Study-1.

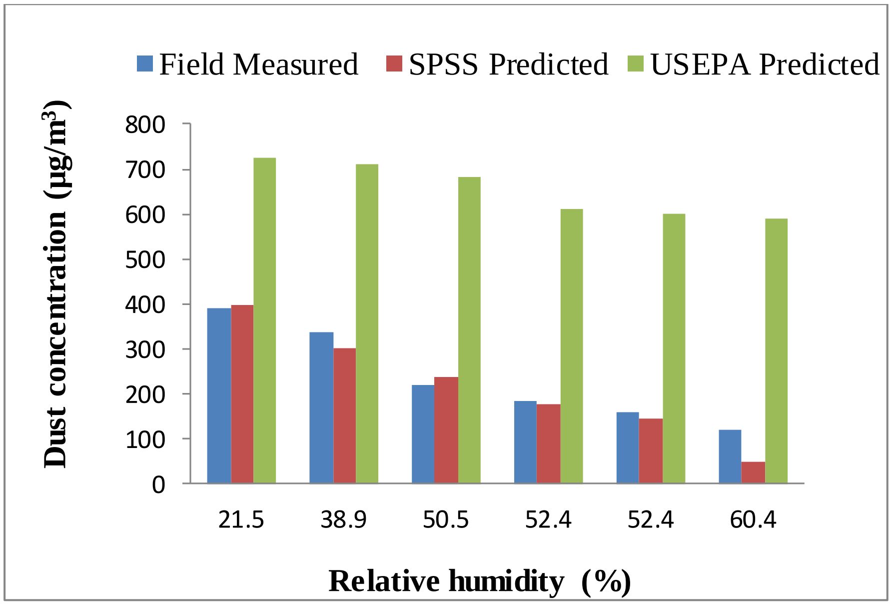


Fig. 4.12 Dust concentration Vs. relative humidity

Table - 4.16 Data used for comparison of dust concentration Vs. relative humidity

Sl. No.	Relative Humidity	Field Measured Concentration	SPSS Predicted Values	USEPA Predicted Values
	(%)	(μg/m^3)	(μg/m^3)	(μg/m^3)
1	21.5	390	397.2	724
2	38.9	338	301.9	710
3	50.5	220	239.1	683
4	52.4	185	177.1	612
5	53.4	160	146.1	600
6	60.4	180	170.8	591

4.4.2 Influence of wind velocity on dust dispersion

Generally, if the air is calm, particulates do not disperse to far off distances. Conversely, if a strong turbulent wind is blowing, particulates emitted / generated will be rapidly dispersed into the atmosphere. The values are compared between field measured concentration and wind velocity (Fig. 4.13). Results show that as wind velocity increases dust concentration increases, and this could be due to more dust dispersion in the atmosphere. The values used for this analysis are given in Table - 4.17. The Case Study-1 data was used for this analysis.

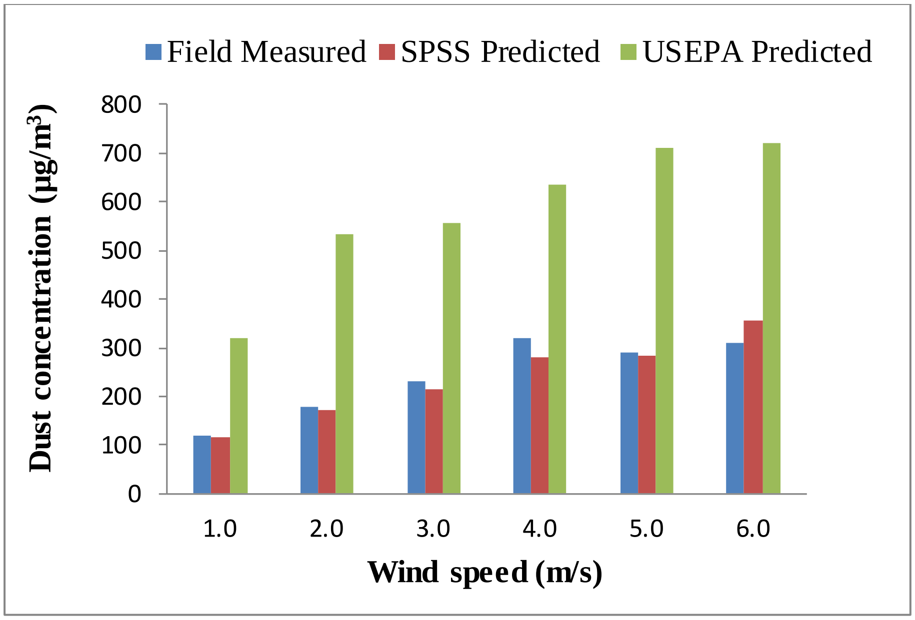


Fig. 4.13 Dust concentration Vs. wind speed

Table - 4.17 Data used for comparison of dust concentration Vs. wind velocity

Sl. No.	Wind Velocity	Field Measured Concentration	SPSS Predicted Values	USEPA Predicted Values
	(m/s)	(µg/m³)	(µg/m³)	(µg/m³)
1	1.1	120	114.4	321
2	1.5	180	170.8	532
3	1.6	230	213.3	558
4	1.8	320	280.2	634
5	2.1	290	285.0	711
6	2.3	310	355.4	722

4.4.3 Influence of distance on dust dispersion

When the pollutants are transported by the wind, concentrations decrease with increase of distance. Dust concentration decreases with the increase of sampler locations (Chaulya, 2004). The modelling results revealed that for a constant wind velocity the dust concentration decreases with increasing distance (Fig. 4.14). This could be due to denser particles settling down at shorter distances and lighter particles dispersing to far distances.

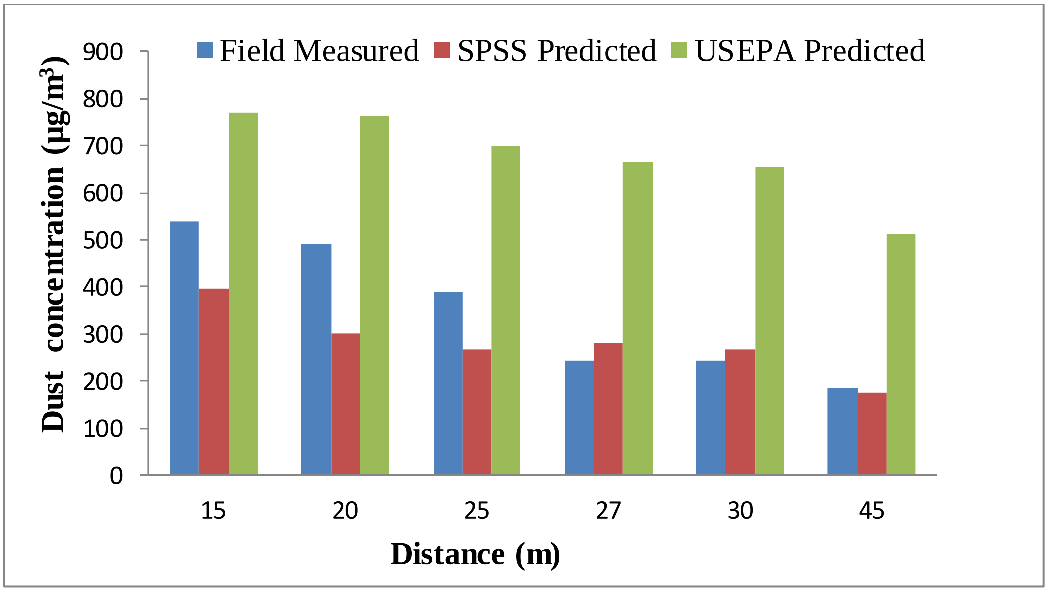


Fig. 4.14 Dust concentration Vs. distance

Table - 4.18 Data used for comparison of dust concentration Vs. distance

Sl. No.	Distance	Field Measured Concentration	SPSS Predicted Values	USEPA Predicted Values
	(m)	(µg/m^3)	(µg/m^3)	(g/s)
1	15	540	397.2	772
2	20	492	301.9	764
3	25	388	268.3	700
4	27	244	280.2	664
5	30	242	268.0	655
6	45	185	177.1	511

4.5 Validation of Developed Models

In order to validate the developed mathematical models to predict dust emission rate and concentration, the results of SPSS model predicted values were compared with field measured values (Tables-4.19 and 4.20). Percentage of error is within 20 percent in both the cases, indicating that developed models are highly satisfactory.

30 out of 73 cases had less than 9 % of error, in 29 cases the error is between 10-14 %, in 14 cases the error is between 15-20 %. The results of emission model prediction values and field measured values and their percentages of errors are given in Table - 4.19. Percentage of errors are distributed out of 73 cases within 20% from emission model are shown in Fig. 4.15.

Table - 4.19 Comparison of field measured dust emission values with SPSS model predicted values

Sl. No.	Field Emission Rate (g/s)	SPSS Model Predicted Emission Rate (g/s)	% of Error
1	0.612	0.550	10.2
2	0.512	0.426	16.7
3	0.162	0.157	03.0
4	0.412	0.375	08.9
5	0.410	0.330	19.5
6	0.481	0.450	06.4
7	0.722	0.642	11.1
8	0.719	0.609	15.3
9	0.678	0.574	15.4
10	0.589	0.492	16.4
11	0.612	0.540	11.8
12	0.282	0.285	01.2
13	0.372	0.363	02.5
14	0.887	0.764	13.9
15	0.726	0.677	06.8
16	0.502	0.428	14.7
17	0.403	0.362	10.1
18	0.422	0.353	16.2
19	0.910	0.737	19.1
20	0.017	0.021	14.0
21	0.123	0.119	03.1
22	0.057	0.050	12.7
23	0.242	0.236	02.4
24	0.254	0.285	12.3
25	0.193	0.177	08.3
26	0.253	0.222	12.2
27	0.223	0.204	08.4
28	0.311	0.269	13.6
29	0.223	0.196	12.2
30	0.218	0.222	01.8
31	0.173	0.155	10.3
32	0.203	0.230	13.4
33	0.111	0.097	12.8
34	0.123	0.123	00.1

Table - 4.19 Comparison of field measured dust emission with SPSS model predicted values cont..

Sl. No.	Field Emission Rate (g/s)	SPSS Model Predicted Emission Rate (g/s)	% of Error
35	0.712	0.654	08.2
36	0.612	0.621	01.5
37	0.688	0.642	06.6
38	0.423	0.479	13.2
39	0.703	0.618	12.1
40	0.911	0.769	15.6
41	0.249	0.293	17.5
42	0.348	0.306	12.0
43	0.371	0.390	05.1
44	0.347	0.397	14.5
45	0.353	0.354	00.1
46	0.471	0.421	10.7
47	0.147	0.168	14.2
48	0.335	0.300	10.6
49	0.263	0.295	12.3
50	0.292	0.265	09.1
51	0.144	0.167	15.9
52	0.141	0.153	08.2
53	0.319	0.337	05.7
54	0.328	0.350	06.8
55	0.252	0.282	11.7
56	0.327	0.336	02.9
57	0.253	0.249	01.4
58	0.383	0.394	02.9
59	0.118	0.108	08.4
60	0.141	0.121	14.3
61	0.328	0.308	06.0
62	0.367	0.317	13.6
63	0.412	0.392	04.8
64	0.344	0.403	17.3
65	0.423	0.383	09.4
66	0.323	0.344	06.4
67	0.930	0.996	09.7
68	0.110	0.117	01.2
69	0.123	0.145	17.7
70	0.128	0.110	13.9

Table - 4.19 Comparison of field measured dust emission with SPSS model predicted values cont..

Sl. No.	Field Emission Rate (g/s)	SPSS Model Predicted Emission Rate (g/s)	% of Error
71	0.303	0.279	07.8
72	0.203	0.224	10.3
73	0.311	0.252	19.1

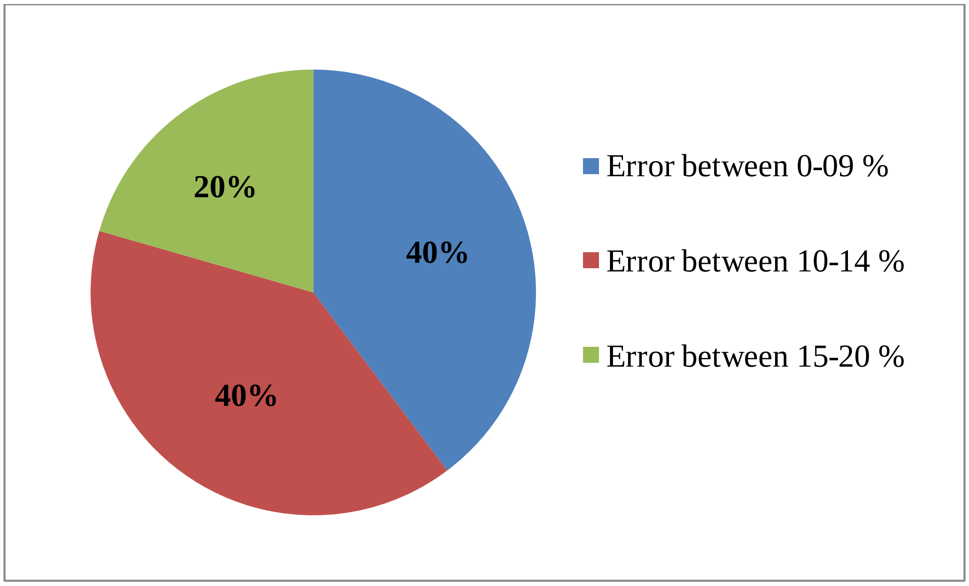


Fig. 4.15 Distribution of % of error for emission model

Similarly, percentage of error for concentration also is within 20%, indicating the developed model is very much satisfactory. Out of 73 cases, about in 19 cases results have less than 9 % error, in 21 cases the error is between 10-14 %, in 33 cases the error is between 15-20 % (Table - 4.17). Fig.4.16 shows that percentage of error distributed out of 73 cases is within 20% from concentration model.

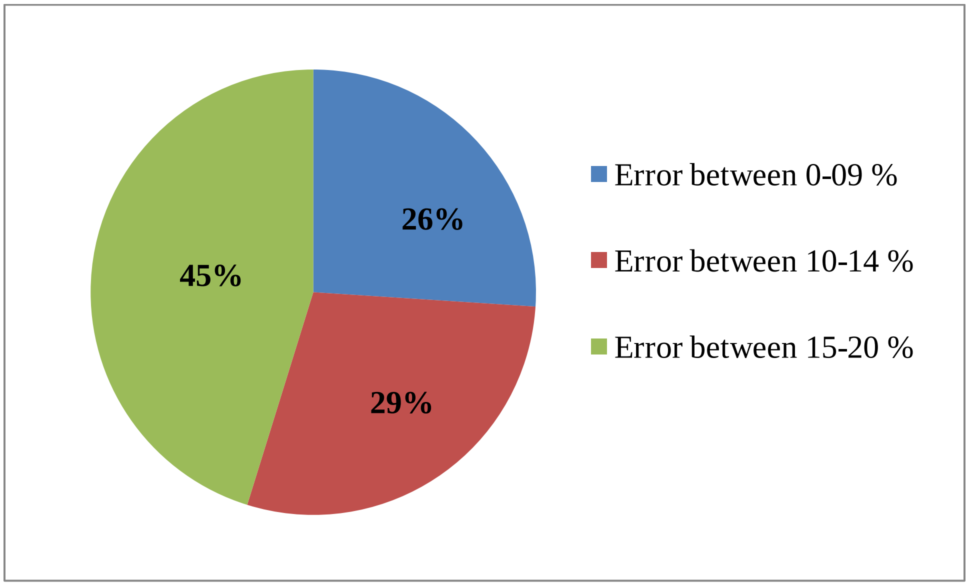


Fig. 4.16 Distribution of % of error for concentration model

Further to validate the developed model, the comparison was made with prediction results of United States of Environmental Protection Agency (USEPA) model. The results of different model predicted values and field measured values are shown in Fig. 4.17. The USEPA model prediction has high error of 99%, whereas, SPSS models predict with an error of 20%, indicating that the models developed are more accurate (Table - 4.20).

Table - 4.20 Comparison of field measured dust concentration values with SPSS model predicted values and USEPA model predicted values

Sl. No.	Field Measured Concentration (µg/m^3)	SPSS Model Predicted Concentration (µg/m^3)	% of Error between Field Measured and SPSS Predicted	USEPA Predicted Concentration (µg/m^3)	% of Error between Field Measured and USEPA Predicted
1	525	422.1	19.6	501.7	22.0
2	419	335.8	19.9	335.0	36.2
3	292	268.7	08.0	219.3	48.5
4	201	183.7	08.6	226.6	37.4
5	111	097.2	12.5	083.9	72.1
6	182	154.5	15.1	034.8	80.3
7	271	251.0	07.4	017.6	91.9
8	217	219.6	01.2	004.4	98.8
9	318	254.6	19.8	001.0	99.6
10	426	352.9	17.2	329.1	12.9
11	339	271.7	19.9	136.7	67.9
12	428	368.9	13.8	481.0	41.9
13	328	283.0	13.7	386.7	22.4
14	511	410.5	19.7	468.1	09.4
15	411	372.4	09.4	290.0	53.4
16	271	229.9	15.2	224.4	59.0
17	342	285.1	16.6	014.3	95.1
18	362	298.9	17.4	353.2	02.7
19	562	485.2	13.7	004.5	98.8
20	292	262.7	10.0	083.2	85.2
21	176	145.6	17.3	072.6	79.1
22	338	298.5	11.7	269.0	35.2
23	359	305.8	14.8	037.7	90.9
24	339	271.8	19.8	009.6	97.8
25	436	375.3	13.9	003.1	99.1
26	302	243.7	19.3	000.4	99.9
27	426	375.0	12.0	250.5	29.8
28	301	272.9	09.3	087.9	83.3
29	478	447.0	06.5	594.8	48.3
30	311	305.2	01.8	345.0	40.3
31	399	341.0	14.5	283.7	31.0

Table - 4.20 Comparison of field measured dust concentration values with SPSS model predicted values and USEPA model predicted values cont..

Sl. No.	Field Measured Concentration (μg/m^3)	SPSS Model Predicted Concentration (μg/m^3)	% of Error between Field Measured and SPSS Predicted	USEPA Predicted Concentration (μg/m^3)	% of Error between Field Measured and USEPA Predicted
32	329	305.3	07.2	228.0	04.4
33	271	236.2	12.8	219.2	19.5
34	302	250.7	17.0	184.6	31.9
35	365	295.5	19.0	057.0	12.7
36	467	402.9	13.7	027.6	27.7
37	311	261.4	16.0	004.5	81.4
38	411	349.3	15.0	001.2	93.5
39	342	301.7	11.8	251.5	98.1
40	222	215.5	02.9	008.8	99.6
41	297	239.2	19.4	012.1	22.7
42	261	231.0	11.5	017.9	59.7
43	255	269.9	05.8	061.4	12.4
44	243	268.5	10.5	000.1	17.9
45	294	274.9	06.5	058.7	06.9
46	250	282.2	12.9	018.5	35.1
47	341	275.7	19.2	005.1	16.6
48	201	204.5	01.7	018.2	95.9
49	226	209.1	07.5	021.2	02.4
50	283	266.2	05.9	027.3	99.2
51	367	294.4	19.8	101.9	73.8
52	302	263.3	12.8	188.3	51.3
53	321	269.2	16.1	021.8	20.4
54	344	277.1	19.4	005.1	89.5
55	344	276.4	19.7	001.8	96.9
56	327	262.1	19.8	000.2	99.3
57	263	282.2	07.3	189.6	99.8
58	299	256.0	14.4	087.9	41.2
59	410	407.5	00.6	143.7	70.8
60	328	268.0	18.3	286.3	24.4
61	290	263.3	18.3	142.6	10.9
62	312	268.4	14.0	152.4	28.9

Table - 4.20 Comparison of field measured dust concentration values with SPSS model predicted values and USEPA model predicted values cont..

Sl. No.	Field Measured Concentration (μg/m^3)	SPSS Model Predicted Concentration (μg/m^3)	% of Error between Field Measured and SPSS Predicted	USEPA Predicted Concentration (μg/m^3)	% of Error between Field Measured and USEPA Predicted
63	229	260.6	13.8	165.9	30.7
64	229	256.7	12.1	106.5	19.1
65	436	370.3	15.1	019.7	38.9
66	257	238.6	07.1	012.5	84.4
67	326	378.0	16.0	002.2	94.0
68	301	275.9	08.3	000.3	98.4
69	478	444.0	07.1	084.7	99.6
70	401	325.2	18.9	045.5	26.5
71	399	338.0	15.3	188.3	96.0
72	329	299.2	09.1	011.2	95.9
73	221	232.5	05.2	006.6	93.1

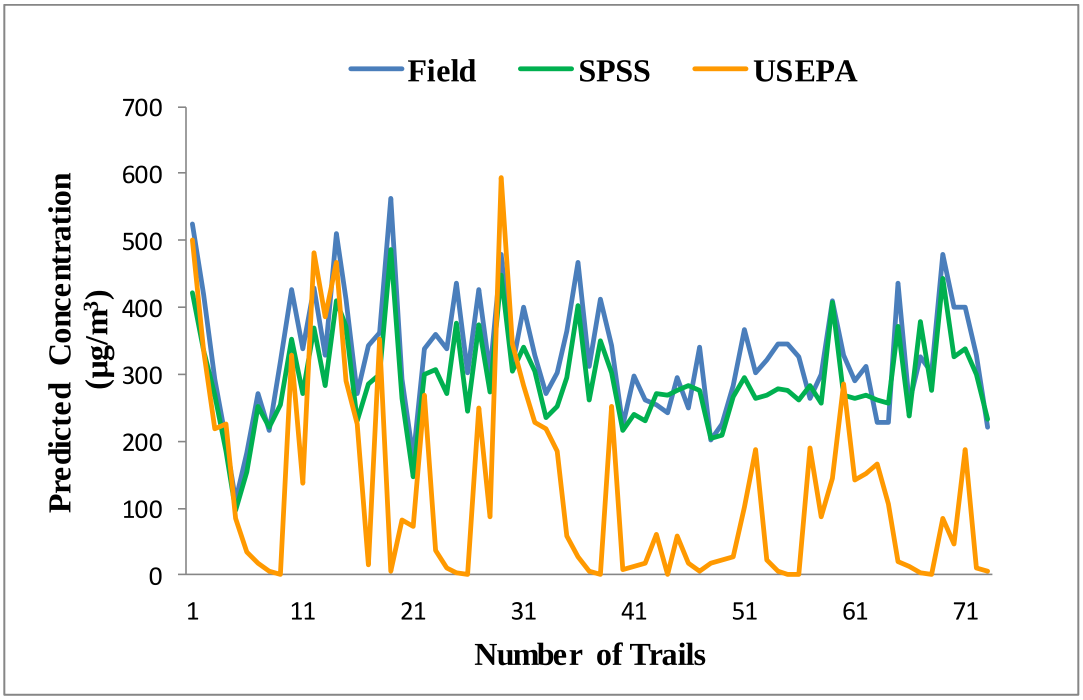
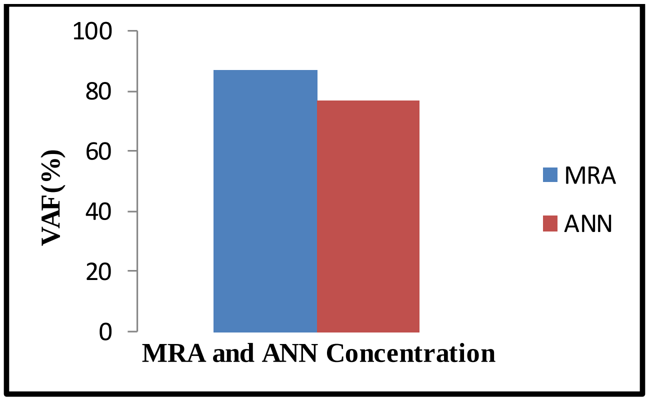


Fig. 4.17 Field concentration values compared with predicted concentrations using different models for drilling operation

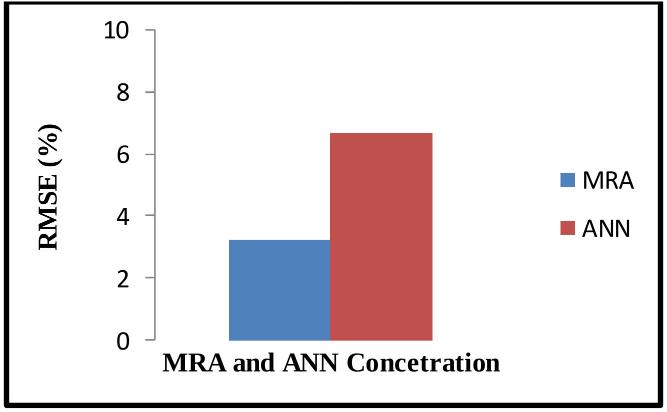
Also the best architecture in each of the ANN methods has been compared with the multiple regression analysis method. The results of comparison are given in Table - 4.21 for concentration model. If the VAF, MAPE is 100 and RMSE is 0, then the model is excellent. The VAF values obtained for MRA is 87.1 %, RMSE is 3.22 and MAPE is 33.7 %. The results are shown in Fig. 4.18. This indicates that SPSS predicted values are statistically more significant than ANN models.

Table - 4.21 Comparison of performance of the developed models of MRA and ANN for concentration model

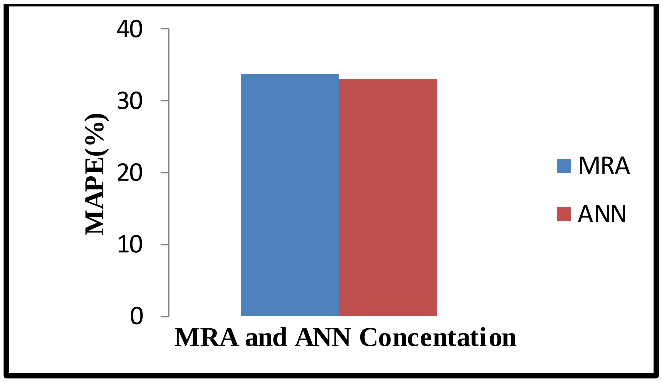
Parameter	**Model**	**VAF**	**RMSE**	**MAPE**
MRA	Concentration	87.1	3.22	33.7
ANN	Concentration	76.9	6.68	33.0



(A)



(B)



(C)

Fig. 4.18 Performance indices of: (a) VAF, (b) MAPE, and c) RMSE, of MRA and ANN for concentration model

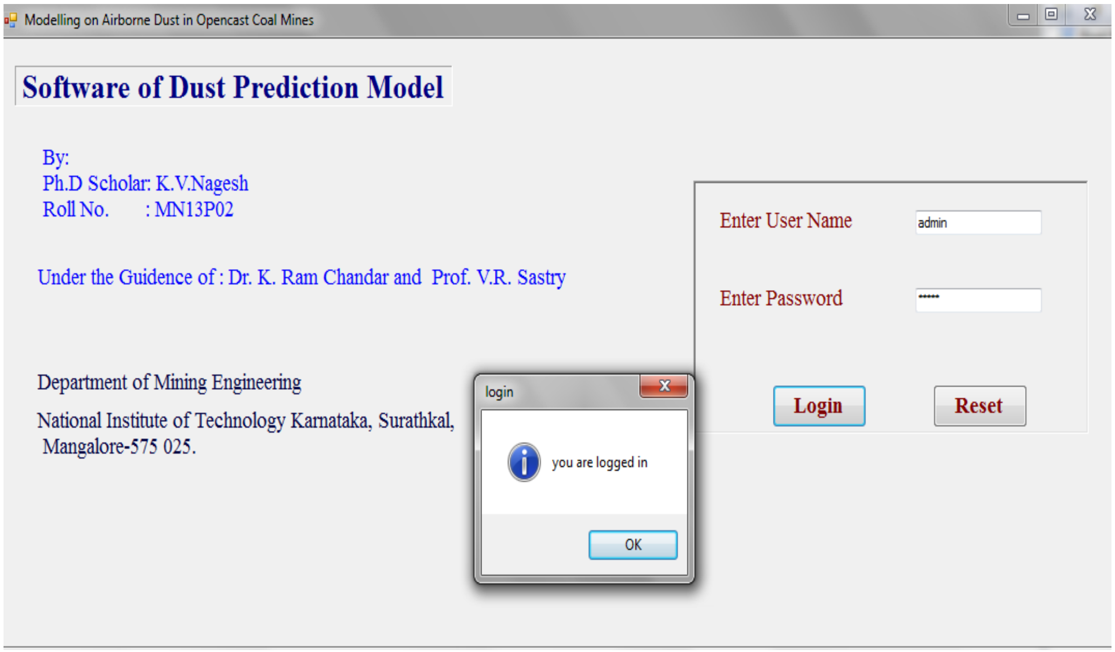
4.6 Development of Dust Prediction Software (Green Software)

A user friendly software was developed to predict dust emission and concentration from drilling operations in surface mines, in Microsoft Visual Basic 6.0. The complete Visual Basic code for this program is given in Appendix-IV. The newly developed software is named as 'Green software'. The software generates expected values of dust emission and concentration from drilling operation on receipt of required parameters such as drill diameter, penetration rate, moisture content, density, compressive strength and rebound hardness value for emission model and distance, temperature, humidity, wind velocity and emission value for concentration model.

The software was developed using equations 4.4 for emission model and 4.5 for concentration model. Figs. 4.19 to 4.23 show the screenshots of the software. Once the software is opened, information is provided via interactive menus. It has menu to select either emission or concentration. In case of emission, it will allow the user to enter input parameters such as drill diameter, penetration rate, moisture content, density and rebound hardness values (Fig. 4.20). After selecting option of 'submit' button in software, it will generate emission value. There after all the input values as well as the generated data are stored in the database.

To get emission value for second trail, clear the existing values in respective slots of variables by clicking on ‘reset’ option and provide new input values. Then after selecting the ‘submit’ option it will generate new emission value and it will store in database. Same procedure has to be followed for remaining trails. After getting enough output results in database, those values can be exported in to excel sheet for further analysis.

Similarly, to get concentration values from software in the main menu, concentration option has to be selected. Later, similar to the emission values, same procedure has to be followed for concentration values.



Modelling on Airborne Dust in Opencast Coal Mines

Software of Dust Prediction Model

By:
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Roll No.   : MN13P02

Under the Guidance of : Dr. K. Ram Chandar and Prof. V.R. Sastry

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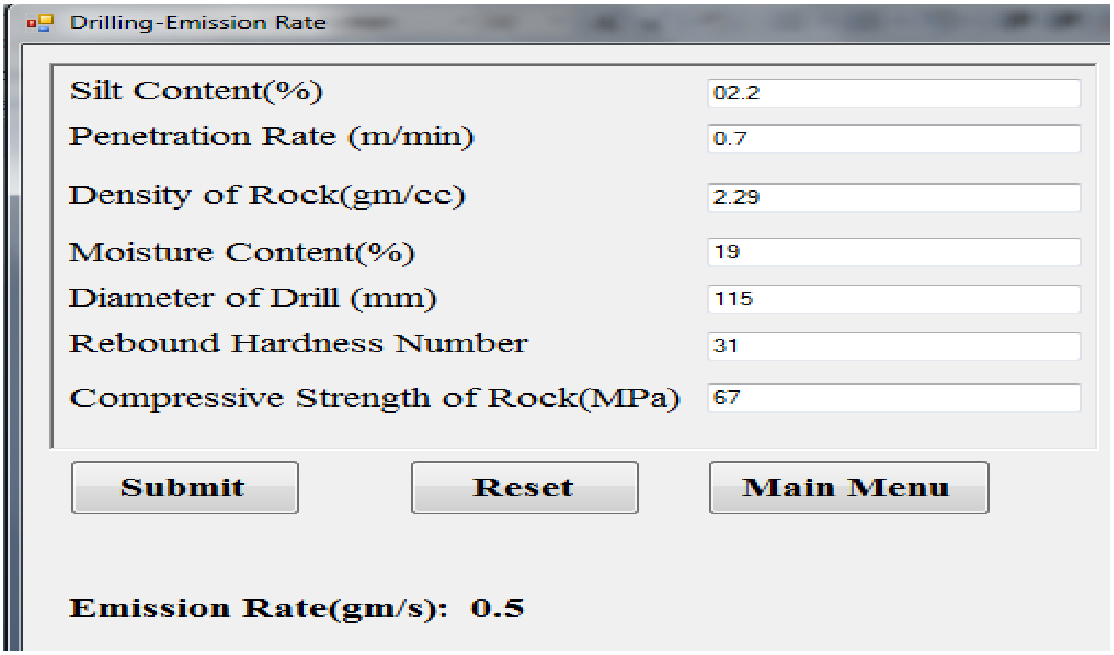
National Institute of Technology Karnataka, Surathkal,
Mangalore-575 025.

Enter User Name: admin
Enter Password: ******

you are logged in

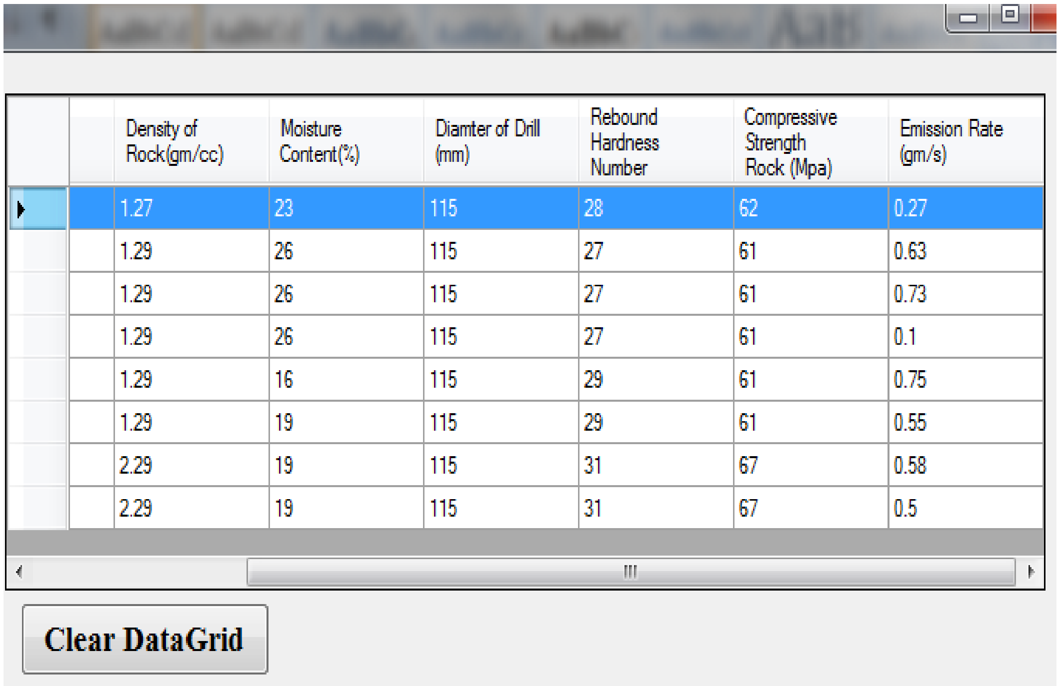
Fig. 4.19 Start up window display of green software



Silt Content(%)	02.2
Penetration Rate (m/min)	0.7
Density of Rock(gm/cc)	2.29
Moisture Content(%)	19
Diameter of Drill (mm)	115
Rebound Hardness Number	31
Compressive Strength of Rock(MPa)	67

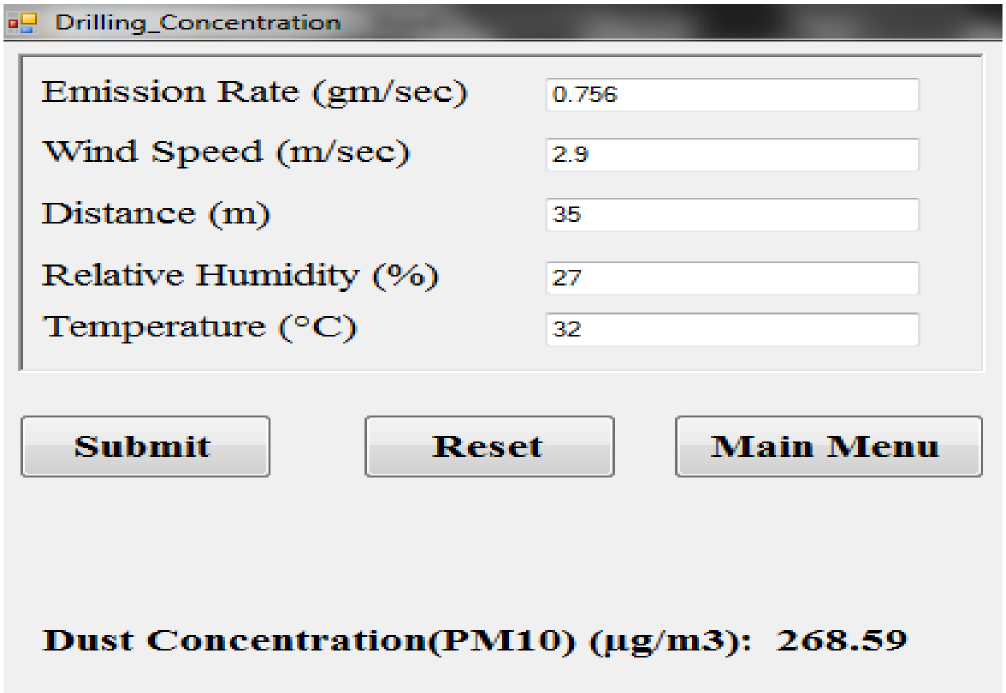
Emission Rate(gm/s): 0.5

Fig. 4.20 Screenshot of finding emission rate in green software



Density of Rock(gm/cc)	Moisture Content(%)	Diamter of Drill (mm)	Rebound Hardness Number	Compressive Strength Rock (Mpa)	Emission Rate (gm/s)
1.27	23	115	28	62	0.27
1.29	26	115	27	61	0.63
1.29	26	115	27	61	0.73
1.29	26	115	27	61	0.1
1.29	16	115	29	61	0.75
1.29	19	115	29	61	0.55
2.29	19	115	31	67	0.58
2.29	19	115	31	67	0.5

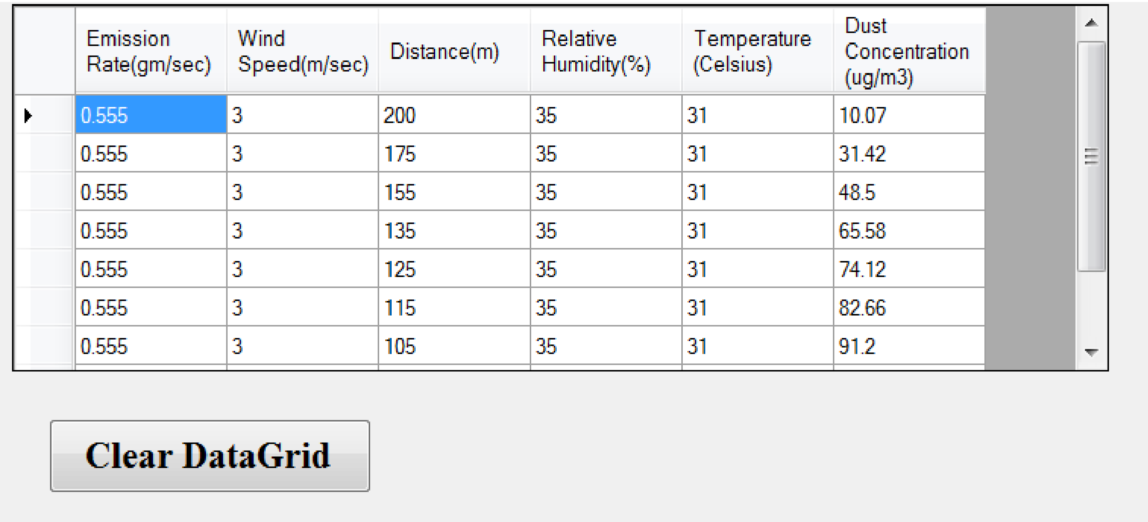
Fig. 4.21 Screenshot of emission rate values stored in green software



Emission Rate (gm/sec) 0.756
Wind Speed (m/sec) 2.9
Distance (m) 35
Relative Humidity (%) 27
Temperature (°C) 32

Dust Concentration(PM10) (µg/m3): 268.59

Fig. 4.22 Input parameters for concentration model



Emission Rate(gm/sec)	Wind Speed(m/sec)	Distance(m)	Relative Humidity(%)	Temperature (Celsius)	Dust Concentration (ug/m3)
0.555	3	200	35	31	10.07
0.555	3	175	35	31	31.42
0.555	3	155	35	31	48.5
0.555	3	135	35	31	65.58
0.555	3	125	35	31	74.12
0.555	3	115	35	31	82.66
0.555	3	105	35	31	91.2

Fig. 4.23 Predicted concentration values stored in green software

CHAPTER - 5

CONCLUSIONS AND SCOPE FOR FURTHER WORK

Extensive field investigations were carried out to develop a dust prediction model for drilling operation in surface mines. Investigations were carried out in three opencast coal mines, two limestone mines and three granite quarries. Data generated from five case studies (from two opencast coal mines, two granite quarries and one limestone mine) was used as input data and one coal mine case study data, one granite quarry data and one limestone mine data was used for validation of the developed models. Various parameters such as moisture content (%), penetration rate (m/min), silt content (%), diameter of drill (mm), rebound hardness number, compressive strength (MPa) and density (g/cc) were considered for emission model. Similarly, emission rate (g/s), wind speed (m/s), distance form source (m), relative humidity (%) and temperature (^oC) were considered for dust concentration model. Physico-mechanical properties of various rocks were determined in the laboratory using ISRM suggested methods.

In total, 169 dust samples were collected for emission and 184 samples were collected for dust concentration. Rock formation wise, 51 sets of data from coal, 40 sets of data from sandstone, 24 sets of data from limestone and 54 sets of data from granite formations were collected for emission model and 43 sets of data from coal, 40 sets of data from sandstone, 47 sets of data from limestone and 54 sets of data from granite formations were collected for concentration model development.

Five case studies of field investigation data (70% of total data, which includes coal, sandstone, limestone and granite formations) were used for model development and three case studies of field investigation data (30% of total data, which include coal, sandstone, limestone and granite formations) were used for model validation.

5.1 Conclusions

The following conclusions are drawn from the research studies:

- Multi-Layer Perceptron neural network was trained using Trainrp, Traincgp, Trainscg and Trainlm algorithms, which are different means of implementing back propagation algorithms. Their performance was compared in terms of RMSE, VAF and MAPE values. Trainlm algorithm gave better performance than all other algorithms in the prediction of dust concentration.
- The coefficient of determination (R^2) value between predicted values from ANN method and field measured values is 0.81 for emission model and 0.80 for concentration model, indicating a very good correlation. This proved that the field generated data is valid.
- Multi Regression Analysis (MRA) models were developed for prediction of dust emission (PM10) and concentration (PM10) using field data. The developed models adequacy is checked by various statistical methods such as ANOVA, VIF and Residual analysis. The developed models are more significant according to statistical methods.
- Developed models are found to accurately predict the dust emission (PM10) and dust concentration (PM10) from drilling operation in surface mines.
- The coefficient of determination (R^2) value between predicted values from SPSS model and field measured values is 0.82 for emission model and 0.81 for concentration model, indicating a very good level of accuracy.
- Based on MRA method, penetration rate and silt content were found to be more influencing the emission rate. Similarly, wind speed and emission rate are exerting more influence on the dust concentration.

- A comparison of MRA method and MLP model using ‘Trainlm’ algorithm revealed that MRA model gave better performance than MLP with lower RMSE and high VAF, MAPE values for all the prediction variables.
- The CFD dust concentrations were compared with the field measured values, the results showing that the percentage of error between CFD predicted and field measured concentration values are between 7.1% and 34.8%.
- Field measured values are compared with the SPSS model predicted values and USEPA predicted values. It was found that USEPA is giving around 99 % error and SPSS model is giving error within 20 %. So, the SPSS model can be used for dust prediction from drilling operations in surface mines under Indian Geo-mining and weather conditions.
- Based on mathematical model developed from multiple regression analysis, user friendly software (Green software) is developed using Microsoft Visual Basic 6.0. The developed software can be used to predict dust emission and concentration from drilling operation in surface mines.

5.2 Scope for Further Work

Although the study provided an insight into the understanding of the dust prediction from drilling operation in surface mines and led to the development of dust prediction models, the subject is still far from being understood comprehensively. The following suggestions are made for carrying out the research further:

1. In the present investigations, Coal, Sandstone, Limestone and Granite formations are considered. In future work, more number of rock formations can be considered for a better prediction.

2. In the present investigation only four types drill diameters were used. This work can be further extended by carrying out studies using other drill diameters.
3. In the present study, regression and ANN modeling techniques are used. However, other techniques such as Adaptive Neuro Fuzzy Inference System (ANFIS), Radial Basis Function (RBF), Fuzzy Logic modeling may be tried. Also, other analysis tools such as Fast Fourier Transformer (FFT) can be used.
4. In the present investigation the models are developed for only drilling operation. Similarly, for other operations also models can be developed in further studies, so that overall dust emission and concentration model for a mine can be developed.

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APPENDIX –I

1.0 Input data for dust emission and concentration model

Table - 1a Input data for dust emission model collected from PKOC-II mine (coal)

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	SPSS Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (g/cm^3)	σc (MPa)	R	E (g/s)	E (g/s)
1	250	0.33	02.8	28.0	1.26	18	23	0.708	0.801
2	250	0.33	20.8	33.0	1.27	16	22	0.498	0.538
3	150	0.28	17.8	26.0	1.24	15	23	0.392	0.346
4	250	0.33	20.2	28.0	1.24	17	20	0.581	0.542
5	250	0.33	18.0	22.2	1.26	17	19	0.452	0.535
6	150	0.28	15.0	24.5	1.25	17	22	0.339	0.395
7	250	0.33	07.9	32.0	1.25	20	21	0.682	0.787
8	250	0.33	08.3	30.0	1.26	17	21	0.684	0.764
9	150	0.28	10.2	29.0	1.22	18	22	0.525	0.540
10	250	0.33	07.9	33.0	1.25	16	23	0.719	0.768
11	250	0.33	08.5	30.0	1.25	17	23	0.721	0.720
12	150	0.28	10.4	28.5	1.24	16	23	0.509	0.511
13	250	0.33	18.0	25.0	1.24	18	20	0.543	0.548
14	250	0.33	18.0	22.2	1.26	18	19	0.556	0.532
15	250	0.33	18.8	30.0	1.26	17	23	0.537	0.522
16	150	0.28	15.0	24.5	1.25	16	22	0.355	0.398
17	250	0.33	07.9	32.0	1.25	17	21	0.682	0.796

Table - 1a Input data for dust emission model collected from PKOC-II mine (coal) conti..

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	SPSS Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (g/cm^3)	σc (MPa)	R	E (g/s)	E (g/s)
18	250	0.33	08.3	30.0	1.26	18	21	0.678	0.761
19	150	0.28	10.2	29.0	1.22	17	22	0.525	0.543
20	250	0.33	07.9	33.0	1.25	20	23	0.679	0.756
21	250	0.33	08.5	30.0	1.25	20	23	0.620	0.711
22	150	0.28	10.4	28.5	1.24	17	23	0.439	0.508
23	250	0.33	16.0	25.0	1.24	17	20	0.567	0.589
24	250	0.33	18.0	22.2	1.26	17	19	0.517	0.535
25	150	0.28	15.0	24.5	1.25	17	22	0.332	0.395
26	250	0.33	07.9	32.0	1.25	18	21	0.682	0.793
27	250	0.33	08.3	30.0	1.26	17	21	0.794	0.764
28	150	0.28	10.2	29.0	1.22	17	22	0.492	0.543
29	250	0.33	07.9	33.0	1.25	18	23	0.779	0.762
30	250	0.33	08.5	30.0	1.25	20	23	0.721	0.711

Table - 1b Input data for dust emission model collected from PKOC-II mine (sandstone)

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	SPSS Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	s (%)	ρ (g/cm^3)	σc (MPa)	R	E (g/s)	E (g/s)
1	250	0.33	18.6	41.1	2.25	38	34	0.077	0.092
2	250	0.33	17.0	26.3	2.28	42	29	0.051	0.044
3	150	0.28	12.5	49.6	2.25	49	31	0.154	0.168
4	250	0.33	08.1	32.6	2.28	38	33	0.215	0.211
5	250	0.33	09.4	37.8	2.35	39	32	0.295	0.243
6	150	0.28	10.2	39.3	2.27	42	28	0.183	0.178
7	250	0.33	08.2	29.2	2.39	41	27	0.279	0.259
8	250	0.33	08.3	31.9	2.25	41	34	0.158	0.177
9	150	0.28	06.2	65.3	2.38	39	34	0.443	0.393
10	150	0.28	12.5	49.2	2.25	42	26	0.324	0.290
11	250	0.33	05.1	32.2	2.38	44	31	0.265	0.261
12	250	0.33	09.4	37.3	2.25	49	34	0.175	0.192
13	150	0.28	02.0	29.3	2.37	47	31	0.119	0.119
14	250	0.33	09.4	37.3	2.25	44	35	0.155	0.186
15	150	0.28	02.0	39.0	2.37	49	34	0.152	0.157
16	250	0.33	08.2	29.0	2.29	47	32	0.179	0.161
17	250	0.33	08.3	31.0	2.25	48	29	0.238	0.251
18	150	0.28	04.2	45.0	2.28	49	28	0.331	0.331
19	150	0.28	12.5	29.0	2.35	47	27	0.324	0.005
20	250	0.33	09.4	37.0	2.35	49	29	0.225	0.267

Table - 2a Input data for dust emission model collected from BOP mine (coal)

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	SPSS Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	s (%)	ρ (g/cm^3)	σc (MPa)	R	E (g/s)	E (g/s)
1	250	0.33	08.3	31.0	1.24	16	23	0.650	0.741
2	150	0.28	10.2	30.0	1.25	18	23	0.565	0.523
3	150	0.28	07.1	39.0	1.25	19	20	0.845	0.740
4	150	0.28	05.6	39.8	1.24	16	19	1.003	0.810
5	150	0.28	09.1	34.0	1.24	17	19	0.652	0.677
6	150	0.33	07.4	38.0	1.26	20	19	0.892	0.802
7	150	0.28	10.3	28.3	1.25	17	19	0.565	0.589
8	150	0.28	07.8	36.2	1.29	16	18	0.695	0.737
9	250	0.33	02.4	46.0	1.26	18	18	1.099	1.112
10	150	0.28	07.1	49.0	1.25	19	20	1.022	0.850
11	150	0.28	07.6	39.8	1.24	16	19	0.928	0.772
12	150	0.28	08.9	34.0	1.24	17	19	0.642	0.681
13	150	0.33	07.4	38.0	1.26	20	19	0.892	0.802
14	150	0.28	07.9	38.8	1.25	17	19	0.665	0.750
15	150	0.28	11.5	34.0	1.24	17	19	0.552	0.631
16	150	0.33	07.4	38.0	1.26	20	19	0.792	0.802
17	150	0.28	07.9	38.8	1.25	17	19	0.617	0.750
18	150	0.28	07.8	36.2	1.29	16	18	0.649	0.737
20	150	0.28	07.1	39.9	1.25	19	20	0.792	0.750
21	150	0.28	07.6	39.8	1.24	16	19	0.654	0.772

Table - 2b Input data for dust emission model collected from BOP mine (sandstone)

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	SPSS Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	s (%)	ρ (g/cm^3)	σc (MPa)	R	E (g/s)	E (g/s)
1	250	0.33	14.2	54.2	2.35	38	31	0.357	0.356
2	250	0.33	12.0	56.3	2.38	49	34	0.333	0.317
3	150	0.28	12.5	69.2	2.35	45	35	0.324	0.286
4	250	0.33	08.1	32.3	2.38	43	33	0.165	0.166
5	250	0.33	09.4	37.4	2.35	46	36	0.125	0.133
6	150	0.28	10.2	49.5	2.37	43	35	0.114	0.113
7	250	0.33	08.2	29.2	2.39	46	31	0.179	0.160
8	250	0.33	08.3	31.3	2.35	47	35	0.118	0.105
9	150	0.28	11.2	55.2	2.38	48	35	0.143	0.139
10	250	0.33	07.9	32.1	2.35	42	31	0.216	0.220
11	250	0.33	08.5	30.2	2.37	44	26	0.310	0.282
12	150	0.28	10.4	58.5	2.39	47	28	0.382	0.338
13	250	0.33	16.0	55.0	2.38	43	27	0.377	0.391
14	250	0.33	02.4	50.2	2.37	47	35	0.370	0.420
17	250	0.33	08.3	39.1	2.38	45	35	0.193	0.154
18	250	0.33	07.9	33.2	2.37	47	35	0.155	0.150
20	250	0.33	08.3	31.3	2.37	46	31	0.166	0.189

Table - 3 Input data for dust emission model collected from Choutapalli limestone mine

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	SPSS Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (g/cm^3)	σc (MPa)	R	E (g/s)	E (g/s)
1	115	0.13	08.9	69.0	2.67	59	27	0.199	0.170
2	115	0.15	08.6	68.0	2.69	62	25	0.221	0.218
3	115	0.15	05.0	59.3	2.69	63	27	0.155	0.145
4	032	0.25	05.5	54.0	2.69	59	28	0.121	0.111
5	115	0.15	08.3	61.0	2.69	63	27	0.102	0.101
6	115	0.15	01.4	54.5	2.63	63	28	0.177	0.156
7	032	0.25	02.6	42.0	2.69	62	24	0.117	0.109
8	115	0.13	06.3	63.0	2.72	62	27	0.131	0.131
9	115	0.16	10.2	69.0	2.71	63	24	0.252	0.223
10	115	0.16	07.1	53.0	2.67	63	24	0.138	0.117
11	032	0.25	11.4	66.0	2.69	71	25	0.199	0.158
12	115	0.15	07.9	54.0	2.52	62	25	0.133	0.122
13	115	0.15	05.4	69.0	2.67	77	25	0.265	0.250
14	115	0.13	03.1	61.0	2.69	71	24	0.282	0.214
15	032	0.25	07.8	64.0	2.69	72	27	0.149	0.159
16	115	0.13	02.4	58.0	2.79	63	28	0.112	0.108
17	115	0.13	04.2	48.8	2.65	68	25	0.027	0.058
18	032	0.25	05.6	56.2	2.63	63	25	0.181	0.200

Table - 3 Input data for dust emission model collected from Choutapalli limestone mine conti..

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	SPSS Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (g/cm^3)	σc (MPa)	R	E (g/s)	E (g/s)
19	115	0.15	02.5	56.0	2.69	74	28	0.123	0.102
20	032	0.25	05.6	54.0	2.63	64	27	0.129	0.131
21	032	0.25	11.9	24.0	2.72	64	27	0.131	0.150
22	032	0.25	06.6	29.0	2.52	66	25	0.121	0.122

Table - 4 Input data for dust emission model collected from M/S Amity Rock Products Private Limited (granite)

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	SPSS Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (g/cm^3)	σc (MPa)	R	E (g/s)	E (g/s)
1	38	0.5	0.25	79.4	2.81	178	27	0.299	0.441
2	34	0.5	0.16	76.8	2.85	167	27	0.219	0.433
3	34	0.5	0.18	79.3	2.62	185	32	0.311	0.362
4	34	0.5	0.22	59.4	2.61	167	30	0.218	0.241
5	34	0.5	0.50	58.4	2.69	185	26	0.197	0.213
6	34	0.5	0.75	62.3	2.91	172	27	0.221	0.231
7	34	0.5	0.91	61.3	2.78	178	29	0.331	0.391
8	34	0.5	0.35	55.2	2.75	196	28	0.214	0.210
9	34	0.5	0.56	56.2	2.61	181	27	0.193	0.220
10	34	0.4	1.56	57.2	2.71	181	31	0.266	0.251
11	34	0.5	1.45	58.3	2.61	194	33	0.213	0.261
12	34	0.5	1.53	59.3	2.77	195	32	0.233	0.246
13	38	0.5	0.65	51.2	2.68	189	33	0.318	0.301
14	38	0.5	1.63	67.2	2.81	178	31	0.271	0.297
15	34	0.5	1.53	52.3	2.69	181	27	0.221	0.237
16	38	0.5	2.30	67.4	2.91	178	28	0.224	0.223
17	38	0.5	2.40	64.2	2.88	177	27	0.199	0.217
18	38	0.5	2.10	67.3	2.75	188	26	0.278	0.280
19	38	0.5	2.90	73.4	2.61	179	27	0.327	0.375

Table - 4 Input data for dust emission model collected from M/S Amity Rock Products Private Limited (granite) conti..

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	SPSS Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (g/cm^3)	σc (MPa)	R	E (g/s)	E (g/s)
20	38	0.5	5.30	73.4	2.71	162	29	0.122	0.122
21	38	0.4	2.40	73.4	2.61	188	39	0.101	0.105
22	38	0.5	2.40	55.0	2.61	182	29	0.121	0.131
23	38	0.5	2.50	55.0	2.69	182	28	0.145	0.129
24	38	0.5	2.10	55.0	2.61	234	28	0.187	0.161
25	38	0.5	0.40	58.0	2.88	217	29	0.166	0.144
26	34	0.5	0.70	58.0	2.75	178	29	0.159	0.167
27	38	0.4	0.40	58.0	2.61	178	27	0.215	0.254
28	38	0.5	1.30	61.0	2.71	188	29	0.193	0.172
29	38	0.5	1.30	61.0	2.81	178	30	0.199	0.156
30	34	0.5	1.90	61.0	2.65	182	30	0.167	0.171

Table - 5 Input data for dust emission model collected from M/S Sadbhav Engineering Private Limited (granite)

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	SPSS Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (g/cm^3)	σ_c (MPa)	R	E (g/s)	E (g/s)
1	115	0.53	2.13	88	2.88	188	39	0.126	0.314
2	115	0.53	2.13	88	2.84	177	31	0.326	0.525
3	115	0.53	2.13	88	2.56	175	27	0.526	0.690
4	115	0.53	2.13	76	2.61	175	28	0.507	0.523
5	115	0.53	2.13	76	2.69	175	27	0.407	0.523
6	115	0.53	2.13	76	2.81	185	26	0.307	0.482
7	115	0.53	2.13	72	2.88	178	27	0.281	0.420
8	115	0.53	2.05	72	2.85	186	29	0.221	0.363
9	115	0.53	2.05	72	2.71	181	39	0.293	0.205
10	115	0.53	2.05	72	2.71	181	31	0.250	0.373
11	115	0.53	2.05	65	2.71	184	27	0.189	0.371
12	115	0.53	2.05	65	2.77	185	28	0.181	0.332
13	115	0.53	3.40	65	2.68	189	27	0.259	0.339
14	115	0.40	3.40	65	2.81	188	26	0.214	0.166
15	115	0.40	3.40	65	2.79	181	27	0.161	0.171
16	115	0.40	3.40	72	2.91	178	29	0.181	0.183
17	115	0.40	3.40	72	2.88	177	22	0.228	0.341
18	115	0.40	3.40	72	2.85	188	29	0.293	0.169

Table - 5 Input data for dust emission model collected from M/S Sadbhav Engineering Private Limited (granite) conti..

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	SPSS Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (g/cm^3)	σ_c (MPa)	R	E (g/s)	E (g/s)
19	115	0.40	3.40	72	2.61	172	28	0.152	0.255
20	115	0.40	3.40	72	2.71	172	28	0.152	0.275
21	115	0.40	3.40	72	2.71	174	29	0.214	0.248
22	115	0.40	3.40	72	2.81	172	29	0.161	0.228
23	115	0.40	3.40	72	2.85	178	27	0.181	0.241
24	115	0.40	3.40	72	2.71	169	29	0.228	0.263

Table - 6a Input data for dust concentration model collected from PKOC-II mine (coal)

Sl. No	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	SPSS Predicted Concentration
	d (m)	T (^{o}C)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (μg/m^3)	C (μg/m^3)
1	15	37.5	21.5	1.8	11.0	18	0.881	340	397.2
2	25	35.5	41.5	2.1	07.5	14	0.788	290	268.3
3	20	37.5	38.9	2.5	07.5	14	0.778	338	301.9
4	18	37.5	38.9	1.5	11.0	18	0.807	330	303.6
5	30	37.5	38.9	2.3	07.5	14	0.935	310	355.4
6	26	36.8	38.7	2.4	07.5	14	0.878	352	330.3
7	27	33.2	50.5	1.8	11.0	18	0.958	320	280.2
8	55	33.6	52.1	2.1	07.5	14	0.887	226	229.5
9	50	33.2	52.4	2.5	07.5	14	0.774	180	187.1
10	32	30.3	60.4	1.5	11.0	18	0.961	210	211.9
11	45	30.3	52.4	2.3	07.5	14	0.816	185	177.1
12	55	30.3	60.4	2.4	07.5	14	0.974	220	208.4
13	100	33.3	50.4	1.8	11.0	18	0.667	110	099.7
14	55	30.3	60.4	1.1	07.5	14	0.783	120	114.4
15	78	35.3	60.4	2.5	07.5	14	0.911	235	214.3
16	18	37.5	38.9	1.5	11.0	18	0.587	230	213.3
17	30	37.5	38.9	2.3	07.5	14	0.935	310	355.4
18	26	36.8	38.7	2.4	07.5	14	0.718	302	264.6

Table - 6a Input data for dust concentration model collected from PKOC-II mine (coal) conti..

Sl. No	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	SPSS Predicted Concentration
	d (m)	T (^oC)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (µg/m^3)	C (µg/m^3)
19	27	33.2	50.5	1.8	11.0	18	0.858	220	239.1
20	45	33.6	52.0	2.1	07.5	14	0.887	226	238.3
21	50	33.2	52.4	2.5	07.5	14	0.674	160	146.1
22	32	30.3	60.4	1.5	11.0	18	0.861	180	170.8

Table - 6b Input data for dust concentration model and collected from PKOC-II mine (sandstone)

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	SPSS Predicted Concentration
	d (m)	T (^oC)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C ($\mu g/m^3$)	C ($\mu g/m^3$)
1	21	24.0	54.2	2.8	7.0	14	0.877	190	159.3
2	13	24.0	54.0	2.2	7.5	14	0.865	170	154.7
3	25	29.0	50.0	2.7	7.5	14	0.706	120	148.6
4	42	30.0	46.3	2.6	7.0	14	0.888	266	229.8
5	29	30.0	44.0	2.5	7.5	14	0.807	252	214.0
6	60	30.0	43.0	2.9	7.5	14	0.705	150	153.7
7	56	30.0	46.4	2.8	7.0	14	0.881	195	217.0
8	10	30.0	46.0	2.2	7.5	14	0.828	215	228.7
9	15	29.0	50.1	2.7	7.5	14	0.993	330	274.6
10	70	30.0	33.0	2.8	7.0	14	0.533	126	106.2
11	75	25.0	49.3	2.3	7.0	14	0.889	126	138.3
12	80	25.0	49.1	2.2	7.0	14	0.881	120	130.2
13	20	21.0	42.1	2.5	7.5	14	0.859	177	158.7
14	25	21.0	32.1	2.1	7.5	14	0.814	188	164.0
15	30	28.9	52.0	2.1	7.0	14	1.161	270	316.3
16	56	30.0	46.0	2.8	7.0	14	0.931	195	238.9
17	10	30.0	46.5	2.2	7.5	14	0.828	215	227.0
18	15	29.0	50.0	2.7	7.5	14	0.793	230	192.8
19	35	28.9	52.8	2.4	7.5	14	0.871	215	194.0
20	40	28.8	44.6	2.2	7.5	14	0.952	210	246.5

Table - 7a Input data for dust concentration model collected from BOP mine (coal)

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	SPSS Predicted Concentration
	d (m)	T (^{o}C)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (μg/m^3)	C (μg/m^3)
1	40	30.3	60.4	1.5	7.5	14	0.803	125	140.2
2	45	30.3	60.4	2.3	7.5	14	0.795	126	142.2
3	25	35.5	41.5	2.4	7.5	14	0.653	220	216.5
4	29	36.8	38.7	2.5	7.5	14	0.859	315	321.1
5	33	37.9	36.0	2.2	7.5	14	0.835	325	324.2
6	34	36.8	38.7	2.3	7.5	14	0.854	335	312.4
7	38	37.9	36.0	2.3	7.5	14	0.691	252	262.0
8	05	27.0	72.0	2.5	7.5	14	0.959	155	174.9
9	06	27.0	72.0	2.9	7.5	14	1.306	320	321.2
10	09	27.0	72.0	2.8	7.0	14	1.217	252	280.9
11	10	27.0	72.0	2.2	7.5	14	1.159	220	249.1
12	12	27.0	72.0	2.7	7.5	14	1.187	210	264.9
13	13	25.0	50.0	2.6	7.0	14	1.201	252	320.6
14	22	25.0	50.0	2.5	7.5	14	1.202	245	312.1
15	18	25.0	50.0	2.9	7.5	14	0.914	220	202.1
16	12	27.0	72.0	2.2	7.5	14	1.329	250	317.2
17	12	27.0	72.0	2.7	7.5	14	1.926	510	568.2
18	16	25.0	50.0	2.6	7.0	14	1.201	252	318.0
19	15	25.0	50.0	2.5	7.5	14	1.290	365	354.2
20	10	27.0	72.0	2.7	7.5	14	1.294	250	310.5

Table - 7b Input data for dust concentration model collected from BOP mine (coal)

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	SPSS Predicted Concentration
	d (m)	T (^{o}C)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (μg/m^3)	C (μg/m^3)
1	40	28.8	44.6	2.2	07.5	14	0.752	140	164.4
2	45	28.8	44.6	2.2	07.5	14	0.935	200	235.2
3	50	27.0	45.3	2.1	07.5	14	0.972	195	224.6
4	55	27.0	45.3	2.2	07.5	14	0.971	220	221.1
5	05	43.0	53.1	3.2	12.0	20	0.772	320	329.4
6	10	43.0	53.1	3.2	12.0	20	0.747	310	314.9
7	15	43.0	53.1	3.2	12.0	20	0.675	280	281.0
8	20	43.0	53.1	3.2	12.0	20	0.603	250	247.2
9	10	43.0	53.1	3.2	12.0	20	0.518	215	220.9
10	20	43.0	53.1	3.2	12.0	20	0.494	205	202.5
11	40	42.0	52.9	3.4	12.0	20	0.628	245	233.4
12	50	42.0	52.9	3.4	12.0	20	0.722	282	263.4
13	65	42.0	52.9	3.4	12.0	20	0.628	245	212.0
14	70	42.0	52.9	3.4	12.0	20	0.743	290	255.0
15	25	42.0	52.9	3.4	12.0	20	0.571	223	222.8
16	35	42.0	52.9	3.4	12.0	20	0.551	215	206.0
18	15	43.0	53.1	3.2	12.0	20	0.625	280	260.5
19	18	43.0	53.1	3.2	12.0	20	0.613	250	253.0
20	10	43.0	53.1	3.2	12.0	20	0.598	215	253.7

Table – 8 Input data for dust concentration model collected from Choutapalli limestone mine

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	SPSS Predicted Concentration
	D (m)	T (^{o}c)	R_h (%)	U (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (µg/m^3)	C (µg/m^3)
1	40	37	32.1	3.7	11.0	18	0.476	229	192.5
2	25	34	40.0	4.1	07.5	14	0.602	187	205.8
3	30	35	37.2	4.1	07.5	14	0.430	167	150.1
4	35	37	32.1	3.7	11.0	18	0.520	192	214.8
5	50	35	37.2	4.1	07.5	14	0.723	269	253.3
6	60	37	32.1	3.7	07.5	14	0.875	322	339.2
7	05	31	48.2	4.0	11.0	18	1.552	510	554.5
8	03	31	48.2	4.0	07.5	14	1.552	525	556.2
9	100	31	48.2	4.0	07.5	14	1.552	401	473.4
10	80	35	37.2	4.1	11.0	18	0.900	319	300.3
11	90	37	32.2	1.8	07.5	14	0.887	263	295.5
12	80	32	46.0	2.9	07.5	14	0.887	262	221.6
13	70	32	46.0	2.9	11.0	18	0.887	268	230.1
14	15	32	46.0	2.9	11.0	18	0.847	291	260.7
15	05	32	44.0	7.2	07.5	14	1.333	453	526.7
16	45	32	44.0	7.2	07.5	14	1.333	501	492.6
17	50	34	36.2	8.3	11.0	18	0.529	225	217.2
18	08	35	35.0	4.2	07.5	18	0.962	435	395.7
19	45	35	35.0	4.2	07.5	18	0.962	435	291.1

Table – 8 Input data for dust concentration model collected from Choutapalli limestone mine conti..

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	SPSS Predicted Concentration
	D (m)	T (^{o}c)	R_h (%)	U (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (µg/m^3)	C (µg/m^3)
20	55	36	32.0	4.0	11.0	18	0.599	251	224.1
21	25	32	43.6	4.3	07.5	14	0.970	331	327.3
22	20	32	43.6	4.3	07.5	14	0.711	257	225.2
23	35	32	43.6	4.3	11.0	18	0.589	189	162.3
24	10	30	50.1	4.3	07.5	14	0.848	212	248.6
25	60	33	46.5	2.9	07.5	14	0.666	171	156.4
26	73	33	46.5	2.9	11.0	18	0.663	173	144.1
27	82	33	46.5	2.9	11.0	18	0.758	182	175.4
28	95	35	43.4	1.4	07.5	14	0.607	129	114.6
29	73	35	43.4	1.4	07.5	14	0.996	283	293.1
30	60	35	43.4	1.4	11.0	18	0.851	261	244.7
31	70	34	44.0	3.4	07.5	14	0.784	251	220.5
32	55	34	44.0	3.4	07.5	14	0.794	262	237.4
33	32	34	44.0	3.4	11.0	18	0.637	214	192.6
34	25	31	48.5	8.6	07.5	14	0.827	289	293.9
35	40	32	44.9	6.8	07.5	14	0.714	266	235.0
36	35	34	40.2	5.8	11.0	18	0.615	262	222.2
37	105	30	54.9	1.4	07.5	14	0.967	151	165.8
38	95	32	47.5	5.8	07.5	14	0.674	152	151.2
39	80	33	42.3	6.1	11.0	18	0.592	156	161.0
40	55	36	32.0	4.0	11.0	18	0.599	241	221.4

Table - 9 Input data for dust concentration model collected from M/S Amity Rock Products Private Limited (granite)

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	SPSS Predicted Concentration
	D (m)	T (°c)	R_h (%)	U (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (μg/m^3)	C (μg/m^3)
1	05	28.3	64.0	1.72	11.0	18	1.116	304	269.3
2	10	28.3	64.0	1.80	07.5	14	1.952	643	609.1
3	15	28.3	64.0	1.80	07.5	14	0.919	162	180.8
4	17	28.3	64.0	1.72	11.0	18	0.826	126	140.0
5	20	30.0	62.0	1.72	07.5	14	0.827	152	161.5
6	22	30.0	62.0	1.72	07.5	14	0.829	177	160.6
7	23	30.0	62.0	1.72	11.0	18	0.715	119	113.0
8	24	30.0	62.0	1.72	07.5	14	0.818	178	154.4
9	25	32.0	61.2	1.88	07.5	14	0.923	227	221.3
10	27	32.0	61.2	1.88	11.0	18	0.912	201	215.1
11	30	32.0	61.2	1.88	07.5	14	0.884	222	201.0
12	30	32.0	41.2	1.88	07.5	14	0.632	178	163.2
13	30	34.2	59.7	4.33	11.0	18	0.839	201	238.9
14	32	34.2	59.7	4.33	11.0	18	0.989	321	298.8
15	33	34.2	59.7	4.33	07.5	14	0.799	222	219.9
16	35	34.2	59.7	4.33	07.5	14	0.983	277	293.7
17	36	27.4	52.5	0.66	11.0	18	0.873	177	159.0
18	36	27.4	72.5	0.66	07.5	14	0.978	150	136.5
19	28	32.4	42.3	2.66	07.5	14	0.863	335	269.5

Table - 9 Input data for dust concentration model collected from M/S Amity Rock Products Private Limited (granite) conti..

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	SPSS Predicted Concentration
	D (m)	T (^{o}c)	R_h (%)	U (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (µg/m^3)	C (µg/m^3)
20	41	31.6	40.4	2.05	11.0	18	0.985	311	299.3
21	45	31.6	40.4	2.05	07.5	14	1.023	341	311.5
22	50	31.6	40.4	2.05	07.5	14	0.941	339	273.6
23	52	28.7	40.4	2.05	11.0	18	1.074	324	297.3
24	56	30.4	40.4	3.86	07.5	14	1.153	326	365.1
25	60	30.4	40.4	3.86	07.5	14	0.897	321	256.6
26	65	30.4	40.4	3.86	07.5	14	0.987	365	289.2
27	65	30.0	53.6	3.86	11.0	18	1.233	376	342.9
28	73	30.0	53.6	3.86	07.5	14	1.222	379	331.5
29	75	30.0	53.6	3.86	07.5	14	1.231	387	333.5

Table - 10 Input data for dust concentration model collected from M/S Sadbhav Engineering Private Limited (granite)

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	SPSS Predicted Concentration
	D (m)	T (^{o}c)	R_h (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (μg/m^3)	C (μg/m^3)
1	05	32.4	44.2	2.2	7.5	14	0.642	198	186.6
2	10	32.4	44.2	2.2	7.5	14	0.542	161	141.3
3	15	32.4	44.2	2.2	7.5	14	0.626	173	171.5
4	17	33.2	43.0	2.9	7.0	14	0.507	157	141.3
5	20	33.2	43.0	2.9	7.5	14	0.507	151	138.8
6	22	33.2	43.0	2.9	7.5	14	0.507	151	137.1
7	23	34.0	41.4	2.6	7.1	14	0.681	189	217.3
8	24	34.0	41.4	2.6	7.5	14	0.421	124	109.8
9	25	34.0	41.4	2.6	7.2	14	0.693	177	220.6
10	27	35.0	47.0	2.1	7.0	14	1.156	365	394.6
11	30	25.0	49.3	2.3	7.0	14	1.289	363	340.9
12	30	35.0	49.1	2.1	7.0	14	1.381	482	477.5
13	30	28.0	62.1	2.8	7.5	14	1.259	282	322.8
14	32	21.0	62.1	2.5	7.5	14	1.214	221	228.6
15	33	28.9	42.0	2.3	7.0	14	0.661	134	143.7
16	35	30.0	46.0	2.3	7.0	14	1.481	501	476.6
17	36	30.0	44.5	2.2	7.5	14	0.628	135	129.3
18	36	29.0	50.0	2.7	7.5	14	0.893	221	216.0
19	28	28.9	42.8	2.1	7.5	14	1.170	387	351.9
20	40	28.8	44.6	2.1	7.5	14	1.152	388	327.4

Table - 10 Input data for dust concentration model collected from M/S Sadbhav Engineering Private Limited (granite) conti..

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	SPSS Predicted Concentration
	D (m)	T (^{o}c)	R_h (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (µg/m^3)	C (µg/m^3)
21	41	21.0	62.1	2.5	7.5	14	1.214	211	220.9
22	45	28.9	42.0	2.3	7.0	14	0.961	209	256.6
23	50	30.0	46.0	2.3	7.0	14	1.033	271	279.9
24	52	30.0	44.5	2.2	7.5	14	1.428	395	444.0

APPENDIX –II

2.0 Validation data for emission and concentration model

Table - 1a Validation data for dust emission model collected from Samaleshwari coal mine (coal)

Sl. No	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	ANN Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	s (%)	ρ (g/cm^3)	σ (MPa)	R	E (g/s)	E (g/s)
1	250	0.33	02.8	22.5	1.25	15	23	0.612	0.526
2	250	0.33	08.5	21.9	1.25	18	23	0.512	0.421
3	150	0.28	24.3	22.1	1.24	21	23	0.162	0.178
4	250	0.33	16.0	25.0	1.24	20	20	0.412	0.319
5	250	0.33	18.0	22.2	1.26	19	19	0.410	0.521
6	150	0.28	15.3	24.5	1.25	17	19	0.481	0.422
7	250	0.33	07.9	32.0	1.25	15	19	0.722	0.711
8	250	0.33	08.3	30.0	1.26	16	19	0.719	0.801
9	150	0.28	12.2	27.3	1.22	13	18	0.678	0.581
10	250	0.33	11.3	33.0	1.25	19	23	0.589	0.599
11	250	0.33	08.3	31.0	1.24	15	23	0.612	0.651
12	150	0.28	22.9	30.0	1.25	16	23	0.282	0.311
13	150	0.28	27.2	39.0	1.25	17	20	0.372	0.362
14	160	0.28	07.6	39.8	1.24	14	19	0.887	0.861
15	150	0.28	08.9	34.0	1.24	17	19	0.726	0.692
16	150	0.33	27.4	38.0	1.26	18	19	0.502	0.511
17	150	0.28	27.9	38.8	1.25	19	19	0.403	0.411
18	150	0.28	27.8	36.2	1.25	20	18	0.422	0.411
19	250	0.28	02.4	36.0	1.26	19	18	0.910	0.971
20	250	0.33	14.2	24.0	2.35	16	34	0.017	0.111
21	250	0.33	17.1	26.0	2.38	17	27	0.123	0.134
22	150	0.28	12.5	29.0	2.35	14	37	0.057	0.121
23	250	0.33	08.1	32.0	2.38	17	32	0.242	0.251
24	250	0.33	09.4	37.0	2.35	18	31	0.254	0.261
25	150	0.28	10.2	29.0	2.37	19	34	0.193	0.216

Table – 1b Validation data for dust emission model collected from Samaleshwari coal mine (sandstone)

Sl. No	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	ANN Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	s (%)	ρ (g/cm^3)	σ (MPa)	R	E (g/s)	E (g/s)
1	250	0.33	08.2	29.0	2.39	41	32	0.253	0.261
2	250	0.33	08.3	31.0	2.35	40	34	0.223	0.238
3	150	0.28	11.2	35.0	2.38	41	32	0.311	0.371
4	250	0.33	07.9	32.0	2.35	42	35	0.223	0.271
5	250	0.33	08.5	30.0	2.37	50	31	0.218	0.327
6	150	0.28	10.4	28.5	2.39	46	34	0.173	0.21
7	250	0.33	16.1	48.0	2.38	44	34	0.203	0.221
8	250	0.33	18.2	42.2	2.37	47	35	0.111	0.132
9	150	0.28	15.1	34.5	2.39	49	34	0.123	0.113
10	250	0.33	07.9	32.0	1.25	38	18	0.712	0.711
11	250	0.33	08.3	30.0	1.26	43	18	0.612	0.522
12	150	0.28	10.2	29.0	1.22	49	17	0.688	0.677
13	250	0.33	07.9	33.0	1.25	48	27	0.423	0.433
14	250	0.33	08.3	31.0	1.24	49	19	0.703	0.711
15	150	0.33	08.2	32.0	1.27	42	17	0.911	0.899

Table - 2 Validation data for dust emission model collected from Yenakandla limestone mine (limestone)

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	ANN Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (g/cm^3)	σc (MPa)	R	E (g/s)	(g/s)
1	115	0.20	00.5	44.0	2.67	63.7	27	0.115	0.119
2	115	0.20	00.5	38.8	2.69	66.7	25	0.101	0.142
3	115	0.20	00.5	57.1	2.69	66.7	27	0.284	0.124
4	115	0.18	02.0	57.2	2.79	58.8	28	0.186	0.201
5	115	0.18	02.0	59.3	2.69	62.5	27	0.229	0.222
6	115	0.18	00.6	54.5	2.63	66.7	28	0.169	0.162
7	115	0.19	00.6	43.1	2.69	58.8	24	0.152	0.163
8	115	0.19	00.9	53.1	2.72	62.5	27	0.174	0.322
9	115	0.19	03.0	51.2	2.71	62.5	24	0.211	0.355
10	115	0.18	04.0	33.0	2.67	66.7	28	0.249	0.231
11	115	0.18	00.2	22.0	2.69	66.7	25	0.348	0.322
12	115	0.18	03.0	32.3	2.69	58.8	25	0.371	0.339
13	115	0.20	00.3	27.0	2.67	62.5	25	0.347	0.371
14	115	0.20	00.8	21.0	2.69	58.8	24	0.353	0.362
15	115	0.20	00.9	34.0	2.69	62.5	27	0.471	0.389
16	115	0.05	07.9	42.2	2.67	63.0	28	0.147	0.189
17	115	0.20	05.6	28.4	2.67	66.7	25	0.335	0.362
18	115	0.18	00.9	23.9	2.69	58.8	27	0.263	0.272
19	115	0.18	07.8	36.0	2.69	62.5	28	0.292	0.301
20	115	0.18	07.0	24.0	2.79	62.5	27	0.144	0.166
21	115	0.15	08.3	28.2	2.67	63.0	27	0.141	0.211
22	115	0.18	00.5	29.0	2.63	66.7	27	0.319	0.339

Table - 2 Validation data for dust emission model collected from Yenakandla limestone mine conti..

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	ANN Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	S (%)	ρ (g/cm^3)	σc (MPa)	R	E (g/s)	(g/s)
23	115	0.18	00.4	22.3	2.69	58.8	24	0.328	0.345
24	115	0.18	00.6	23.2	2.72	62.5	27	0.252	0.921
25	115	0.18	00.5	23.4	2.71	66.7	24	0.327	0.347
26	115	0.18	00.8	21.4	2.67	58.8	28	0.253	0.333
27	115	0.17	00.9	31.2	2.69	62.5	25	0.383	0.371
28	115	0.15	16.9	37.2	2.71	63.0	26	0.118	0.123
29	115	0.18	12.5	24.2	2.67	58.8	25	0.141	0.162
30	115	0.25	02.4	22.6	2.69	62.5	28	0.328	0.119

Table - 3 Validation data for dust emission model collected from M/S Swamy Ayyapa Crusher Private Limited (granite)

Sl. No.	Diameter	Penetration Rate	Moisture Content	Silt Content	Density	Compressive Strength	Rebound Hardness Number	Field Emission Rate	ANN Predicted Emission Rate
	d (mm)	P (m/min)	m (%)	s (%)	ρ (g/cm^3)	σ_c (MPa)	R	E (g/s)	(g/s)
1	32	0.15	2.5	69.2	2.88	179	33	0.367	0.357
2	32	0.15	2.1	69.2	2.71	165	32	0.412	0.442
3	32	0.15	2.1	69.2	2.72	175	30	0.344	0.314
4	32	0.15	2.1	69.2	2.71	175	31	0.423	0.463
5	32	0.15	2.1	58.2	2.79	175	27	0.323	0.343
6	32	0.15	2.1	59.2	2.71	185	38	0.930	0.561
7	32	0.15	2.1	51.3	2.78	178	39	0.110	0.210
8	32	0.15	2.1	61.3	2.75	176	38	0.123	0.193
9	32	0.15	2.1	61.3	2.71	181	39	0.128	0.198
10	32	0.15	2.0	61.3	2.71	181	31	0.303	0.333
11	32	0.15	2.1	58.3	2.61	175	33	0.203	0.233
12	32	0.15	2.0	59.2	2.77	175	32	0.311	0.321
13	32	0.15	2.0	59.2	2.68	179	30	0.273	0.269
14	32	0.15	2.4	48.2	2.81	175	31	0.152	0.159
15	32	0.15	2.4	39.2	2.69	175	27	0.112	0.119
16	32	0.19	2.4	47.4	2.71	178	38	0.052	0.132
17	32	0.19	2.4	54.2	2.78	181	39	0.043	0.043
18	32	0.19	2.6	57.3	2.75	175	39	0.103	0.103
19	32	0.19	2.6	39.2	2.61	175	27	0.211	0.231
20	32	0.19	2.6	39.2	2.71	179	29	0.117	0.137
21	32	0.19	2.6	58.2	2.71	175	39	0.112	0.192
22	32	0.19	2.6	39.2	2.71	175	29	0.134	0.164
23	32	0.19	3.4	41.3	2.79	181	28	0.123	0.173

Table - 4a Validation data for dust concentration model collected from Samaleshwari coal mine (coal)

Sl. No	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Concentration Rate	ANN Predicted Concentration
	d (m)	T (^{O}c)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (µg/m^3)	C (µg/m^3)
1	10	42.3	38.9	3.2	12	20	0.912	525	491
2	15	42.3	38.9	3.2	12	20	0.712	419	399
3	20	42.3	38.9	3.1	12	20	0.562	292	218
4	10	39.0	38.9	3.2	12	20	0.412	201	222
5	20	39.0	38.9	3.2	12	20	0.222	111	139
6	40	39.0	40.0	3.2	12	20	0.412	182	162
7	50	41.0	40.0	3.1	12	20	0.622	271	241
8	60	41.0	40.0	2.9	12	20	0.572	217	227
9	70	41.0	40.0	2.9	12	20	0.678	318	271
10	20	42.0	40.0	2.9	12	20	0.789	426	374
11	30	42.0	40.0	2.9	12	20	0.612	339	261
12	06	42.0	38.6	3.1	12	20	0.782	428	326
13	08	38.0	38.6	3.2	12	20	0.672	328	283
14	16	38.0	38.6	3.1	12	20	1.002	511	421
15	24	38.0	38.6	3.1	12	20	0.926	411	322
16	15	42.0	38.6	3.1	12	20	0.462	271	229
17	52	42.0	38.9	3.2	12	20	0.673	342	261
18	10	42.0	38.9	3.1	12	20	0.622	362	262
19	64	41.0	38.9	3.2	12	20	1.210	562	401
20	35	41.0	40.1	3.2	12	20	0.617	342	288
21	29	41.0	40.2	3.1	12	20	0.323	176	155

Table – 4b Validation data for dust concentration model collected from Samaleshwari coal mine (sandstone)

Sl. No	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Concentration Rate	ANN Predicted Concentration
	d (m)	T (^{O}c)	RH (%)	u (m/s)	σ_Z (m)	σ_y (m)	E (g/s)	C (μg/m^3)	C (μg/m^3)
1	20	41.0	38.6	3.0	12	20	0.667	338	272
2	45	42.5	40.1	3.0	12	20	0.712	359	287
3	55	40.5	38.1	3.0	12	20	0.634	339	281
4	65	40.5	40.1	3.0	12	20	0.923	436	375
5	75	40.5	40.1	3.0	12	20	0.623	302	263
6	25	42.5	38.1	3.0	12	20	0.823	426	375
7	35	42.5	40.1	3.0	12	20	0.611	301	272
8	05	44.5	40.0	3.0	12	20	0.923	478	447
9	10	44.5	40.0	3.0	12	20	0.588	311	205
10	15	43.5	30.4	3.2	12	20	0.603	399	341
11	20	44.5	40.0	3.2	12	20	0.603	329	305
12	10	43.5	40.0	3.3	12	20	0.411	271	236
13	20	44.5	40.0	3.1	12	20	0.473	302	250
14	40	44.5	37.8	2.9	12	20	0.612	365	295
15	50	41.5	40.0	2.9	12	20	0.912	467	402
16	60	41.5	40.0	2.9	12	20	0.588	311	261
17	70	41.5	40.0	2.9	12	20	0.823	411	349
18	20	44.5	40.0	2.9	12	20	0.603	342	301
19	30	44.5	40.0	3.0	12	20	0.411	222	215

Table - 5 Validation data for dust concentration model collected from Yenkandla limestone mine

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	ANN Predicted Concentration
	D (m)	T (^{o}c)	R_h (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (µg/m^3)	C (µg/m^3)
1	36	31	37	1.94	11.0	18	0.819	297	239
2	50	31	37	1.94	07.5	14	0.828	261	231
3	56	33	31	2.5	07.5	14	0.822	255	222
4	60	33	31	2.5	11.0	18	0.827	243	268
5	65	33	31	2.5	11.0	18	0.853	294	274
6	75	34	29	2.5	07.5	14	0.851	250	282
7	23	34	29	2.5	07.5	14	0.727	341	275
8	65	31	43	2.2	11.0	18	0.835	201	204
9	73	31	43	2.2	07.5	14	0.863	226	209
10	45	31	29	2.2	07.5	14	0.832	283	266
11	40	31	43	2.2	11.0	18	1.002	367	294
12	35	33	36	2.2	11.0	18	0.811	302	263
13	32	33	36	2.2	07.5	14	0.819	321	269
14	27	33	36	2.2	07.5	14	0.828	344	277
15	25	33	36	2.2	11.0	18	0.822	344	276
16	52	34	33	1.1	07.5	14	0.827	327	262
17	41	34	33	1.1	07.5	14	0.853	263	271
18	38	34	33	1.1	11.0	18	0.783	299	256
19	24	23	43	1.94	07.5	14	1.448	410	407
20	36	23	43	1.94	07.5	14	1.133	328	268
21	22	23	43	1.94	11.0	18	1.028	290	288

Table - 6 Validation data for dust concentration model collected from quarry of M/S Swamy Ayyapa Crusher Private Limited (granite)

Sl. No.	Distance	Temperature	Relative Humidity	Wind Speed	Sigma (z)	Sigma (y)	Field Emission Rate	Field Measured Concentration	ANN Predicted Concentration
	D (m)	T (°c)	R_h (%)	u (m/s)	σ_z (m)	σ_y (m)	E (g/s)	C (µg/m^3)	C (µg/m^3)
1	20	38.0	38.6	3.0	12	20	0.667	312	301
2	45	38.0	40.1	3.0	12	20	0.712	229	260
3	55	41.0	38.1	3.0	12	20	0.634	229	263
4	65	42.0	40.1	3.0	12	20	0.923	436	404
5	75	42.0	40.1	3.0	12	20	0.623	257	281
6	25	42.8	38.1	3.0	12	20	0.823	326	351
7	35	42.8	40.1	3.0	12	20	0.611	301	287
8	05	44.2	40.0	3.0	12	20	0.923	478	431
9	10	44.2	33.0	3.0	12	20	0.588	401	389
10	15	44.2	30.4	3.2	12	20	0.603	399	377
11	20	41.0	30.4	3.0	12	20	0.603	329	362
12	10	41.0	30.4	3.3	12	20	0.411	221	242
13	20	41.0	30.4	3.1	12	20	0.473	302	288
14	40	38.0	37.8	2.9	12	20	0.212	165	149
15	50	38.0	37.8	2.9	12	20	0.412	117	109
16	60	38.0	37.8	2.9	12	20	0.288	092	091
17	70	38.0	40.0	2.9	12	20	0.223	061	088
18	20	38.0	40.0	2.9	12	20	0.203	087	098
19	30	38.0	40.0	3.0	12	20	0.211	081	092
20	20	37.0	38.6	3.0	12	20	0.467	212	192
21	45	37.5	40.1	3.0	12	20	0.212	059	061
22	55	37.5	38.1	3.0	12	20	0.434	159	144
23	65	37.5	40.1	3.0	12	20	0.223	036	046

APPENDIX – III

3.0 Description for ISCST3 model

Industrial Source Complex Short Term Model (ISCST3) equation for prediction of dust concentration developed by USEPA.

$$X = \frac{QKVD}{2\pi u_s \sigma_y \sigma_z} \exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right] \quad \text{--------(Equation-1)}$$

where,

X = Concentration (µg/m^3)

Q = Pollutant emission rate (g/s)

K = 1000000 default value

D = Decay term (dimensionless)

V = Vertical term

σy & σz = Standard deviation of lateral & vertical concentration distribution

u_s = Mean wind speed (m/s)

y = Crosswind distance from source to receptor (m)

Calculation of crosswind distance from source to receptor (y): The crosswind distance y to the receptor from the plume centerline is given by:

$$y = \left[X(R) - X(S)\right]\cos(WD) - \left[Y(R) - Y(S)\right]\sin(WD) \quad \text{------(Equation-2)}$$

where,

y = Crosswind distance (m)

X(R) = x coordinate of receptor (m)

Y(R) = y coordinate of receptor (m)

X(S) = x coordinate of source (m)

Y(S) = ‘y’ coordinate of source (m)

WD = Direction from which wind is blowing (angle measured clockwise from north) (degrees)

Calculation of the Dispersion Parameters ($\sigma_y;\sigma_z$): The dispersion parameters used in equation 1 are calculated as below:

$$\sigma_y = 465.11628(x)\tan(TH) \qquad \text{-----(Equation-3)}$$

where,

$$TH = 0.017453293\left[c - d\ln(x)\right] \qquad \text{------(Equation-4)}$$

where,

x = Downwind distance (Km)

c, d = Coefficients, the coefficients c and d (Table 1)

Table - 1 Coefficient default values for Standard deviation of lateral concentration distribution (σ_y)

Pasquill Stability Category	c	d
A	24.167	2.5334
B	18.333	1.8096
C	12.500	1.0857
D	8.333	0.72382
E	6.250	0.054287
F	4.1667	0.36191

The Pasquill stability category refers to the stability of air layers near the ground. It is based upon wind speed and insolation (incoming solar radiation). The following Table 2 defines the six categories.

Table - 2 Pasquill-Gifford stability categories

Surface Wind (m/s) (measured at 10 m)	**Daytime Insolation**			**Nighttime Cloudiness**	
	Strong	Moderate	Slight	Thinly overcast or ≥ 4/8 cloudiness	≤ 3/8 cloudiness
< 2	A	A – B	B	-	-
2 – 3	A – B	B	C	F	F
3 – 5	B	B – C	C	D	E
5 – 6	C	C – D	D	D	D
>6	C	D	D	D	D

A-Extremely unstable; B-Moderately unstable; C-Slightly unstable;D-neutral; E-Slightly stable; F-Moderately stable.

NOTE: Insulation is the rate of radiation from the sun received per unit of earth's surface. Strong insolation corresponds to sunny midday in summer. Slight insolation corresponds to similar conditions in winter. For A–B, B–C, and C–D, average values are taken. Regardless of wind speed, the neutral category D should be assumed for overcast conditions during.

$$\sigma_z = ax^b \qquad \text{------(Equation-5)}$$

where,

x = Downwind distance (Km)

a, b = Coefficients, the coefficients a and b (Table - 3)

Table - 3 Coefficient values for standard deviation vertical concentration distribution (σ_z) (EPA, 1995)

Pasquill Stability Category	x (km)	a	b	Pasquill Stability Category	x (km)	a	b
A	< 0.1	122.8	0.944	E	< 0.1	24.26	0.8366
	0.1-0.15	158.08	1.054		0.1-0.3	23.331	0.81956
	0.16-0.2	170.22	1.093		0.31-1	21.628	0.7566
	0.21-0.25	179.52	1.126		1.01-2	21.628	0.63077
	0.26-0.3	217.41	1.264		2.01-4	22.534	0.57154
	0.31-0.4	258.89	1.409		4.01-10	24.703	0.50527
	0.41-0.5	346.75	1.728		10.01-20	26.97	0.46713
	0.51-3.11	453.85	2.116		20.01-40	35.42	0.37615
	> 3.11	-	-		>40	47.618	0.29592

Table - 4 Coefficient values for standard deviation vertical concentration distribution (σ_z) (Cont'd)

Pasquill Stability Category	x (km)	a	b	Pasquill Stability Category	x (km)	a	b
B	< 0.2	90.6	0.9319	F	< 0.2	15.209	0.81558
	0.21-0.4	98.4	0.9833		0.21-0.7	14.457	0.78407
	>0.4	109.3	1.097		0.71-1	13.953	0.68465
C	All	61.14	0.9145		1.01-2	13.953	0.63227
D	< 0.3	34.45	0.8697		2.01-3	14.823	0.54503
	0.31-1	32.09	0.8106		3.01-7	16.187	0.4649
	1.01-3.0	32.09	0.6440		7.01-15	17.836	0.41507
	3.01-10	33.50	0.6048		15.01-30	22.651	0.32681
	10.01-30	36.65	0.56589		30.01-60	27.074	0.27436

Calculation of Vertical Term (V): The vertical term includes the vertical dispersion parameter (σ_z) and mixing height. In this study, the mixing heights were obtained from the User's Guide for the fugitive dust model. Therefore, the vertical term is then given by:

$$V = \frac{\sigma_z \sqrt{2\pi}}{z_i}$$ -----------(Equation-6)

where,

σ_z = Vertical dispersion parameter (m)

Z_i = Mixing height (m)

Calculation of Decay Term (D): The following formula is used to determine decay tem.

$$D = \exp(-\psi \frac{x}{u_s}) \quad \text{for} \quad \psi > 0$$ --------(Equation-7)

$$D = 1 \quad \text{for} \quad \psi = 0$$

where,

ψ = Decay coefficient

$$\psi = \frac{0.693}{T_{1/2}}$$ --------(Equation-8)

where,

$T_{1/2}$ = Pollutant half-life (s)

X = Downwind distance (m)

u_s = Mean wind speed (m/s)

The default value for ψ is 0

APPENDIX - IV

4.0 Visual Basic code for the development of Software

Visual Basic code was used for development of Green Software

```
PublicClass Form1

PrivateSub Button1_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Button1.Click
If TextBox1.Text = "admin"And TextBox2.Text = "admin"Then
            MsgBox(" you are logged in",
MsgBoxStyle.Information, " login")
            Form2.Show()
Me.Show()
ElseIf TextBox1.Text = "krc"And TextBox2.Text =
"krc123"Then
            MsgBox(" you are logged in",
MsgBoxStyle.Information, " login")
            Form2.Show()
Me.Show()
ElseIf TextBox1.Text = ""And TextBox2.Text = ""Then
            MsgBox(" No username and/or password found",
MsgBoxStyle.Critical, " Error")
ElseIf TextBox1.Text = ""Then
            MsgBox(" No username found",
MsgBoxStyle.Critical, " Error")
ElseIf TextBox2.Text = ""Then
            MsgBox(" No password found",
MsgBoxStyle.Critical, " Error")
Else
            MsgBox(" Invalid username and/or password",
MsgBoxStyle.Critical, " Error")
EndIf
EndSub

PrivateSub Button2_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Button2.Click
        TextBox1.Text = ""
        TextBox2.Text = ""
EndSub
```

```
PrivateSub Form1_Load(ByVal sender As System.Object, ByVal
e As System.EventArgs) HandlesMyBase.Load
        Label1.Text = "Software of Dust Prediction Model"
        Label4.Text = "Under the Guidence of : Dr. K. Ram
Chandar and  Prof. V.R. Sastry "
        Label5.Text = "Department of Mining Engineering"
        Label6.Text = "National Institute of Technology
Karnataka, Surathkal, "& Environment.NewLine &" Mangalore-
575 025."
        Label7.Text = " By: "& Environment.NewLine &" Ph.D
Scholar: K.V.Nagesh "& Environment.NewLine &" Roll No.:
MN13P02"


EndSub
EndClass


PublicClass Form2

PrivateSub EmissionToolStripMenuItem_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs)
'Drilling emission Rate
        form3.Show()
Me.Hide()
EndSub


PrivateSub Button1_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Button1.Click
        Form1.Show()
Me.Close()
EndSub

PrivateSub EmissionRateToolStripMenuItem_Click(ByVal sender
As System.Object, ByVal e As System.EventArgs) Handles
EmissionRateToolStripMenuItem.Click
        form3.Show()
Me.Close()

EndSub
```

```
PrivateSub ConcentrationToolStripMenuItem_Click(ByVal
sender As System.Object, ByVal e As System.EventArgs)
Handles ConcentrationToolStripMenuItem.Click
        Drilling_Concentration.Show()
Me.Close()

EndSub

PrivateSub Form2_Load(ByVal sender As System.Object, ByVal
e As System.EventArgs) HandlesMyBase.Load

EndSub
EndClass

PublicClass form3
PrivateSub Button1_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Button1.Click
If TextBox1.Text = ""Or TextBox2.Text = ""Or TextBox3.Text
= ""Or TextBox4.Text = ""Or TextBox5.Text = ""Or
TextBox6.Text = ""Or TextBox7.Text = ""Then
            MsgBox("Please enter all values")
EndIf

Dim Ed AsNewDouble'Ed-Emission Rate for drilling
Dim s AsNewDouble's-silt content(%)
Dim pr AsNewDouble'pr-penetration rate(m/min)
Dim dr AsNewDouble'Dr-Density of Rock(gm/cc)
Dim mc AsNewDouble'mc-moisture(%)
Dim rh AsNewDouble'rh-rebound hardness number
Dim cs AsNewDouble'CS-Compressive srength(MPa)
Dim dd AsNewDouble'dd-diameter of drill(mm)

'Label7.Text = "Emission Rate"

        s = (Val(TextBox1.Text))
        pr = (Val(TextBox2.Text))
        dr = (Val(TextBox3.Text))
        mc = (Val(TextBox4.Text))
        dd = (Val(TextBox5.Text))
        rh = (Val(TextBox6.Text))
        cs = (Val(TextBox7.Text))


Dim temp1 AsNewDouble
Dim temp2 AsNewDouble
```

```
 Ed = 0.754 + (0.001 * dd) - (0.019 * mc) + (1.252 * pr) +
(0.011 * s) - (0.021 * rh) - (0.003 * cs) - (0.0265 * dr)

        Ed = Math.Round(Ed, 2)


        Label7.Text = "Emission Rate(gm/s):  " +
Convert.ToString(Ed)

        DataGridView1.Rows.Add(TextBox1.Text,
TextBox2.Text, TextBox3.Text, TextBox4.Text, TextBox5.Text,
TextBox6.Text, TextBox7.Text, Ed)
EndSub

PrivateSub Button2_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Button2.Click
        TextBox1.Text = ""
        TextBox2.Text = ""
        TextBox3.Text = ""
        TextBox4.Text = ""
        TextBox5.Text = ""
        TextBox6.Text = ""
        TextBox7.Text = ""
        Label7.Text = ""
EndSub

PrivateSub Button3_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Button3.Click
        Form2.Show()
Me.Close()
EndSub

PrivateSub form3_Load(ByVal sender As System.Object, ByVal
e As System.EventArgs) HandlesMyBase.Load

EndSub

PrivateSub Label7_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Label7.Click

EndSub


PrivateSub Button4_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Button4.Click
```

```
        DataGridView1.Rows.Clear()
EndSub
EndClass
```

```
PublicClass Drilling_Concentration

PrivateSub Button1_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Button1.Click
If TextBox1.Text = ""Or TextBox2.Text = ""Or TextBox3.Text
= ""Or TextBox4.Text = ""Or TextBox5.Text = ""Then
            MsgBox("Please enter all values")
EndIf

Dim cd AsNewDouble'Cd-Concentration for Drilling
Dim Ed AsNewDouble'Ed-Emission Rate for drilling
Dim ws AsNewDouble'ws-wind speed(m/s)
Dim d AsNewDouble'd-distance between source to monitor
point (m)
Dim rh AsNewDouble'rh-Relative Humidity(%)
Dim t AsNewDouble't-temperature(celcius)


        Ed = (Val(TextBox1.Text))
        ws = (Val(TextBox2.Text))
        d = (Val(TextBox3.Text))
        rh = (Val(TextBox4.Text))
        t = (Val(TextBox5.Text))


        cd = (410.464 * Ed) - (0.854 * d) + (11.968 * ws) +
(10.057 * t) - (3.28 * rh) - 279.806


        cd = Math.Round(cd, 2)


        Label7.Text = "Dust Concentration(PM10) (µg/m3):  "
+ Convert.ToString(cd)

        DataGridView1.Rows.Add(TextBox1.Text,
TextBox2.Text, TextBox3.Text, TextBox4.Text, TextBox5.Text,
cd)
```

```
EndSub

PrivateSub Button2_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Button2.Click
        TextBox1.Text = ""
        TextBox2.Text = ""
        TextBox3.Text = ""
        TextBox4.Text = ""
        TextBox5.Text = ""
        Label7.Text = ""
EndSub

PrivateSub Button3_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Button3.Click
        Form2.Show()
Me.Close()
EndSub

PrivateSub Button4_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Button4.Click
        DataGridView1.Rows.Clear()
EndSub

PrivateSub Drilling_Concentration_Load(ByVal sender As
System.Object, ByVal e As System.EventArgs)
HandlesMyBase.Load

EndSub
EndClass
```

List of Publications based on Ph. D Research work

Sl. No.	Title of the Paper	Authors	Name of the Journal/Conference /Symposium, Vol., No., Pages	Year of Publication
1	Prediction and Analysis of Dust Dispersion from Drilling Operation in Opencast Coal Mine	V.R. Sastry , K. Ram Chandar, K.V. Nagesha	Procedia Earth and Planetary Science, Vol-11, pp-303-311. (Published in Science Direct).	2015
2	Prediction of Dust Dispersion by Drilling Operation Using Artificial Neural Networks	K.V.Nagesha, K. Ram Chandar, and V.R. Sastry	International Journal of Prevention & Control of Industrial Pollution, Vol-1, pp- 1-13.	2015
3	Prediction of Dust Dispersion during Drilling Operation in Opencast Coal Mines: A Multi Regression Model	K.V. Nagesha, V.R. Sastry and K. Ram Chandar	International journal of Environmental Sciences, Vol-6, pp-591-606.	2015

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International Journal Papers:

1. V.R. Sastry, K. Ram Chandar, K.V. Nagesha, E. Muralidhar and Md. Sheob Mohiuddin. (2015). "Prediction and Analysis of Dust Dispersion from Drilling Operation in Open Cast Coal Mine". Procedia Earth and Planetary Science. Vol-11, pp-303-311. (Published in Science Direct).

2. K.V. Nagesha, K. Ram Chandar, and V.R. Sastry, (2015). Prediction of Dust Dispersion by Drilling Operation Using Artificial Neural Networks. International Journal of Prevention and Control of Industrial Pollution, Vol-1, pp- 1-13.

3. K.V. Nagesha, V.R. Sastry and K. Ram Chandar, (2015). Prediction of dust dispersion during drilling operation in open cast coal mines: A multi regression model. International journal of Environmental Sciences. Vol-6, pp-591-606.

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