Prediction of Dust Dispersion by Drilling Operation Using Artificial Neural Networks

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Abstract

During various stages of mining, a large quantity of dust generates and disperses into the atmosphere. Apart from all activities, the dust generated by drilling activity usually in fugitive form and it will have more harmful particulate matters. It is necessary to identify emission rate and concentration of dust from drilling operation. The modeling of dust dispersion in the ambient air is a tool used for prediction and simulation of dust concentration level in the ambient air. In this paper, Artificial Neural Network (ANN) approach is used for development of airborne dust model for drilling operation in opencast coal mines. Field investigations were carried out in three large opencast coal mines in India, and the data used for developing dust prediction models via ANN. The correlation coefficients for emission and concentration models are 0.96 and 0.78 respectively, which shows better predictability by ANN method.

Keywords: ANN and PM10, concentration, dust dispersion models, emission

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INTRODUCTION

Extraction of coal from the earth is increasing day by day to meet the demand for coal for various industries and it plays a major role in nation development. During extraction of coal by surface mining method, more dust will be dispersed into the atmosphere.[1] Various major dust sources are categorized into three types, namely point source, line source and area source.[2]

The drilling activity is one of the point sources, produces very harmful particulate matter, which is having PM10 and PM2.5. The various empirical formulas were formulated by United States of Environmental Protection Agency (USEPA) to predict the dust emission and concentration levels in atmospheric. These models were not able to predict the dust levels under Indian Geo-mining conditions.[3]

The workers working near to mining operations breathe airborne dust, which causes development of various respiratory diseases. The people who have prolonged exposure and inhalation of airborne respirable coal dust particles may lead to the accumulation of dust in the lungs which leads to pneumoconiosis.[4]

It is necessary to know the dust concentration level in the ambient environment. So that various control techniques can be implemented in the mine to reduce the dust concentration. Many dust control techniques have been developed to reduce dust generation and dispersion at the working places of the mine.[5] Some of control techniques are like water spraying continuously on the haul roads, wet drilling, etc.[6] Artificial

Neural Network (ANN) is one of the most powerful prediction tool so far and has a very wide variety of applications in environmental related tasks.[7] Literature shows that very few researches have focused on statistical tool for making of dust model using ANN method. The ANN is not only for dust prediction application it also used for determining of O_3, SO_2, H_2S, NOx, NO_2, NO and CO in the atmosphere.[8]

Cheng *et al*.[9] have concluded that ANN is not only for prediction of ambient air quality application; this method can be used for comparison to other statistical methods like regression methods.

Baawain *et al*.[10] have concluded that ANN method tools are more significant when there will be a more collinearity between input variables. In recent days more focus on development of type of training algorithms for environmental problems. Generally there are two methods are available, like feed forward networks and feedback network.[8]

The ANN mainly consists of neurons connected by link and each link has a numeric weight.[11] The ANN can be usefulness when system becomes non-linear working condition and it recognize the pattern, learn task and solves problem. Generally to develop models by ANN, the three layers neural network and back propagation algorithm was commonly used.[12]

MATERIALS AND METHODS

To develop dust prediction models the air borne dust monitoring was done in three opencast coal mines. In the first step the field investigations were carried out in mine-1 and mine-2. This data was used for model development and another data of coal mine-3 was used for validation of the models. To monitor the air born dust emission and concentration by the drilling operation, three personal dust monitors and two ambient samplers were used. Initially to know the background concentration of the source, one instrument was placed in the upwind direction from the source. At the end of the sampling, some of coal samples were collected and brought to laboratory and determined various rock properties. Both the mines were operated by wagon drills, having 150mm and 250mm diameter and were used for drilling the blast holes in the coal benches. These drills were drilled at a penetration of 0.28m/min to 0.33 m/min.

Meteorological parameters are important factors for any dispersion model. It is the main component in determining the diluting effect of the atmosphere as the released substance is carried along by the wind.[13] The meteorological data was obtained from metrological station, which was installed in the mine site.

To develop models, drilling operation parameters, distance from drilling point to monitoring point, rock properties, silt content, dispersion coefficients, emission and meteorological parameters were used as inputs. The field investigations in mine-1 and mine-2 were used for model development using Artificial Neural Network.

Parameters Influencing for Coal Dust of PM10

Drilling diameters: To monitor dust emission by drilling operation on coal benches, wagon drills are having diameters 150 and 250 mm were used. Penetration rate: The wagon drills are drilled on coal benches with an average depth of 5 to 6m from the ground level and at penetration rate was varied from 0.28 to 0.33m/min. Silt content: Silt content is the fine particles present in the drill cutting was determined.

It is expressed in percentage. Dispersion coefficients: The coal dust produced by drilling operation, initially the dust plume raised and dispersed based on dispersion coefficients, which were determined, based on downwind distance from the source to receptor using Pasquill-Gifford formula.[14] Rock properties: The rock properties play a major role in the dust emission.

The properties are density, compressive strength, hardness number and moisture content. All the rock properties were determined based on the International Society for Rock Mechanics (ISRM) suggested methods.

To determine all these properties some coal samples were collected from different coal benches. Compressive strength: The compressive strength of a coal was determined indirectly by using both Protodyakanov's strength index and point load test. Hardness number: To know the resistance offered to the coal, the hardness number was determined by using a rebound hardness tester.

Moisture content: To determine the moisture present in the drill cuttings, initially, some amount of drill cuttings samples was taken and placed in an oven for 24 hours at a temperature of 102 °C. Finally, sample was removed and allowed for cooling and taken the final weight. The ratio between final weight and initial weight is the moisture content.

Dust Monitoring and Data Collection

In this research work to develop emission model and concentration model by Artificial Neural Network, the field investigations were carried out in three mines. To monitor dust of PM10 by drilling operation in coal benches, two mines from north India and one mine from south India were selected.

A typical broad view of three open cast coal mines and dust monitoring equipment placed near to drilling operation are shown in Figures 1 and 2. Total 51 samples were collected from emission from two mines. The dust emission values are ranging from 0.170 to 1.499 gm/sec. Similarly 42 samples were collected to develop concentration model. The values are ranging from 120 to 352μg/m^3.

The third mine field investigation data were used for validation. Total 21 emission values were collected for emission model which ranged between 0.222 – 1.210 gm/sec, similarly 21 samples were collected for validation of concentration model ranging between 275 and 662 μg/m^3.

Details of field investigations of Mine-1 are given in Tables 1 and 2, mine-2 details are given in Tables 3 and 4 and mine-3 details are given in Tables 5 and 6. At the end of the monitoring some rock samples were collected from different locations and determined various properties. Rock properties and the details are given in the respective mine tables.

(A)

(B)

(C)

Fig. 1. *Typical Broad View of Three Open Cast Coal Mines.*

(A)

(B)

(C)

Fig. 2. *Personal Dust Samplers and Ambient Point Samplers Placed Near to Drilling Activity.*

Table 1. *Dust Emission Parameters and Dust Emission Values Monitored in Mine-1.*

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 (gm/sec)**
1	250	0.33	02.8	32.0	1.25	15	23	0.758
2	250	0.33	08.5	30.0	1.25	16	23	0.520
3	150	0.28	10.4	28.5	1.24	15	23	0.539
4	250	0.33	16.0	25.0	1.24	17	20	0.227
5	250	0.33	18.0	22.2	1.26	17	19	0.170
6	150	0.28	15.0	24.5	1.25	17	22	0.345
7	250	0.33	07.9	32.0	1.25	20	21	0.782
8	250	0.33	08.3	30.0	1.26	17	21	0.794
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	0.679
11	250	0.33	08.5	30.0	1.25	17	23	0.621
12	150	0.28	10.4	28.5	1.24	16	23	0.539
13	250	0.33	16.0	25.0	1.24	18	20	0.223
14	250	0.33	18.0	22.2	1.26	18	19	0.216
15	250	0.33	16.0	30.0	1.26	17	23	0.217
16	150	0.28	15.0	24.5	1.25	16	22	0.345

17	250	0.33	07.9	32.0	1.25	17	21	0.782
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	0.520
22	150	0.28	10.4	28.5	1.24	17	23	0.539
23	250	0.33	16.0	25.0	1.24	17	20	0.227
24	250	0.33	18.0	22.2	1.26	17	19	0.217
25	150	0.28	15.0	24.5	1.25	17	22	0.432
26	250	0.33	07.9	32.0	1.25	18	21	0.712
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	0.592
29	250	0.33	07.9	33.0	1.25	18	23	0.679
30	250	0.33	08.5	30.0	1.25	20	23	0.621

Table 2. *Dust Dispersion Parameters and Dust Concentration Monitored in Mine-1.*

Sl. no.	**Distance**	**Temperature**	**Relative humidity**	**Wind speed**	**Sigma (z)**	**Sigma (y)**	**Field emission rate**	**Field measured concentration**
	d (m)	**T (°C)**	**RH (%)**	**u (m/s)**	**σ_z (m)**	**σ_y (m)**	**E (gm/sec)**	**C (μg/m^3)**
1	15	35.5	41.5	1.8	11.0	18	0.380	340
2	25	35.5	41.5	2.1	07.5	14	0.200	290
3	20	37.5	38.9	2.5	07.5	14	0.278	338
4	18	37.5	38.9	1.5	11.0	18	0.307	330
5	30	37.5	38.9	2.3	07.5	14	0.235	319
6	26	36.8	38.7	2.4	07.5	14	0.278	352
7	27	33.2	50.5	1.8	11.0	18	0.358	320
8	45	33.6	52.1	2.1	07.5	14	0.087	166
9	50	33.2	52.4	2.5	07.5	14	0.074	180
10	32	30.3	60.4	1.5	11.0	18	0.261	280
11	45	30.3	60.4	2.3	07.5	14	0.216	285
12	55	30.3	60.4	2.4	07.5	14	0.174	220
13	100	30.3	60.4	1.8	11.0	18	0.167	150
14	125	30.3	60.4	2.1	07.5	14	0.083	170
15	135	30.3	60.4	2.5	07.5	14	0.111	135
16	18	37.5	38.9	1.5	11.0	18	0.307	330
17	30	37.5	38.9	2.3	07.5	14	0.235	310
18	26	36.8	38.7	2.4	07.5	14	0.278	352
19	27	33.2	50.5	1.8	11.0	18	0.358	320
20	45	33.6	52.0	2.1	07.5	14	0.087	126
21	50	33.2	52.4	2.5	07.5	14	0.074	190
22	32	30.3	60.4	1.5	11.0	18	0.261	310

Table 3. *Dust Emission Parameters and Dust Emission Monitored in Mine-2.*

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 (%)	P (gm/cm^3)	σc (MPa)	R	E (gm/sec)
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	0.765
3	150	0.28	07.1	39.0	1.25	19	20	0.945
4	150	0.28	07.6	39.8	1.24	16	19	1.263
5	150	0.28	08.9	34.0	1.24	17	19	0.452
6	250	0.33	07.4	38.0	1.26	20	19	0.392
7	150	0.28	07.9	38.8	1.25	17	19	0.365
8	150	0.28	07.8	36.2	1.29	16	18	0.695
9	250	0.33	02.4	36.0	1.26	18	18	1.499
10	150	0.28	07.1	39.0	1.25	19	20	1.300
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	0.342
13	250	0.33	07.4	38.0	1.26	20	19	0.392
14	150	0.28	07.9	38.8	1.25	17	19	0.365
15	150	0.28	08.9	34.0	1.24	17	19	0.452
16	250	0.33	07.4	38.0	1.26	20	19	0.492
17	150	0.28	07.9	38.8	1.25	17	19	0.217
18	150	0.28	07.8	36.2	1.29	16	18	0.549
20	150	0.28	07.1	39.0	1.25	19	20	0.992
21	150	0.28	7.6	39.8	1.24	16	19	1.114

Table 4. *Dust Dispersion Parameters and Dust Concentration Monitored in Mine-2.*

Sl. no.	Distance	Temperature	Relative humidity	Wind speed	Sigma (z)	Sigma (y)	Field emission rate	Field measured concentration
	d (m)	T (°C)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (gm/sec)	C (μg/m^3)
1	40	30.3	60.4	1.5	7.5	14	0.303	325
2	45	30.3	60.4	2.3	7.5	14	0.095	126
3	25	35.5	41.5	2.4	7.5	14	0.253	320
4	29	36.8	38.7	2.5	7.5	14	0.259	315
5	33	37.9	36.0	2.2	7.5	14	0.235	325
6	34	36.8	38.7	2.3	7.5	14	0.254	335
7	38	37.9	36.0	2.3	7.5	14	0.191	252
8	05	27.0	72.0	2.5	7.5	14	0.259	315
9	06	27.0	72.0	2.9	7.5	14	0.306	320
10	09	27.0	72.0	2.8	7.0	14	0.217	252
11	10	27.0	72.0	2.2	7.5	14	0.159	220
12	12	27.0	72.0	2.7	7.5	14	0.187	210
13	13	25.0	50.0	2.6	7.0	14	0.201	252
14	22	25.0	50.0	2.5	7.5	14	0.202	245
15	18	25.0	50.0	2.9	7.5	14	0.314	120
16	12	27.0	72.0	2.2	7.5	14	0.329	220
17	12	27.0	72.0	2.7	7.5	14	0.926	210
18	16	25.0	50.0	2.6	7.0	14	0.201	252
19	15	25.0	50.0	2.5	7.5	14	0.290	245
20	10	27.0	72.0	2.7	7.5	14	0.294	210

Table 5. *Dust Emission Parameters and Dust Emission Monitored in Mine-3.*

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 (gm/sec)
1	250	0.33	2.84	32.0	1.25	15	23	0.912
2	250	0.33	08.5	30.0	1.25	18	23	0.712
3	150	0.28	10.4	28.5	1.24	21	23	0.562
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	0.222
6	150	0.28	15.3	24.5	1.25	17	19	0.412
7	250	0.33	07.9	32.0	1.25	15	19	0.622
8	250	0.33	08.3	30.0	1.26	16	19	0.572
9	150	0.28	10.2	29.0	1.22	13	18	0.678
10	250	0.33	07.9	33.0	1.25	19	23	0.789
11	250	0.33	08.3	31.0	1.24	15	23	0.612
12	150	0.28	10.2	30.0	1.25	16	23	0.782
13	150	0.28	07.1	39.0	1.25	17	20	0.672
14	160	0.28	07.6	39.8	1.24	14	19	1.002
15	150	0.28	08.9	34.0	1.24	17	19	0.926
16	150	0.33	07.4	38.0	1.26	18	19	0.462
17	150	0.28	07.9	38.8	1.25	19	19	0.673
18	150	0.28	07.8	36.2	1.25	20	18	0.622
19	250	0.28	02.4	36.0	1.26	19	18	1.210
20	250	0.33	07.9	33.0	1.25	19	23	0.617
21	250	0.33	08.3	30.0	1.26	16	19	0.323

Table 6. *Dust Dispersion Parameters and Dust Concentration Monitored in Mine-3.*

Sl. no.	Distance	Temperature	Relative humidity	Wind speed	Sigma (z)	Sigma (y)	Field emission rate	Field concentration rate
	d (m)	T (°C)	RH (%)	u (m/s)	σ_z (m)	σ_y (m)	E (gm/sec)	C (μg/m^3)
1	10	45	38.9	3.2	12	20	0.912	625
2	15	45	38.9	3.2	12	20	0.712	426
3	20	45	38.9	3.1	12	20	0.562	362
4	10	45	38.9	3.2	12	20	0.412	431
5	20	45	38.9	3.2	12	20	0.222	276
6	40	46	40.0	3.2	12	20	0.412	317
7	50	46	40.0	3.1	12	20	0.622	378
8	60	46	40.0	2.9	12	20	0.572	387
9	70	46	40.0	2.9	12	20	0.678	501
10	20	46	40.0	2.9	12	20	0.789	526
11	30	46	40.0	2.9	12	20	0.612	593

12	6	47	38.6	3.1	12	20	0.782	498
13	8	47	38.6	3.2	12	20	0.672	528
14	16	47	38.6	3.1	12	20	1.002	623
15	24	47	38.6	3.1	12	20	0.926	547
16	15	47	38.6	3.1	12	20	0.462	489
17	52	46	38.9	3.2	12	20	0.673	463
18	10	45	38.9	3.1	12	20	0.622	428
19	64	45	38.9	3.2	12	20	1.210	662
20	35	46	40.1	3.2	12	20	0.617	548
21	29	45	40.2	3.1	12	20	0.323	275

RESULTS AND DISCUSSION

To develop model in the Artificial Neural Network (ANN) there was no such rules to define the architecture like considering of number of hidden nodes in the model. To get final model, basically there are three fundamental components which are important, like transfer function, network architecture and learning regulations. The Multi-Layer Perceptron (MLP) of feed forward method with back propagation algorithm is used as neural network architecture. Initially the input values are feed through input neurons and followed by hidden neurons which process through transfer function. Finally the output values are obtained from output neuron. Two models were formulated using ANN, Model-1 is for predicting Emission rate and Model-2 is for predicting concentration of dust. The analysis was carried out for different combinations of hidden layers and the network showing the least root mean square error was selected here. The input data has been divided in to two types like training data is used to train the network and validation data is used to implement of the early stopping technique because of to avoid over fitting to the training data. A typical architectures and input variables are shown in Figures 3, 4 and Tables 7, 8.

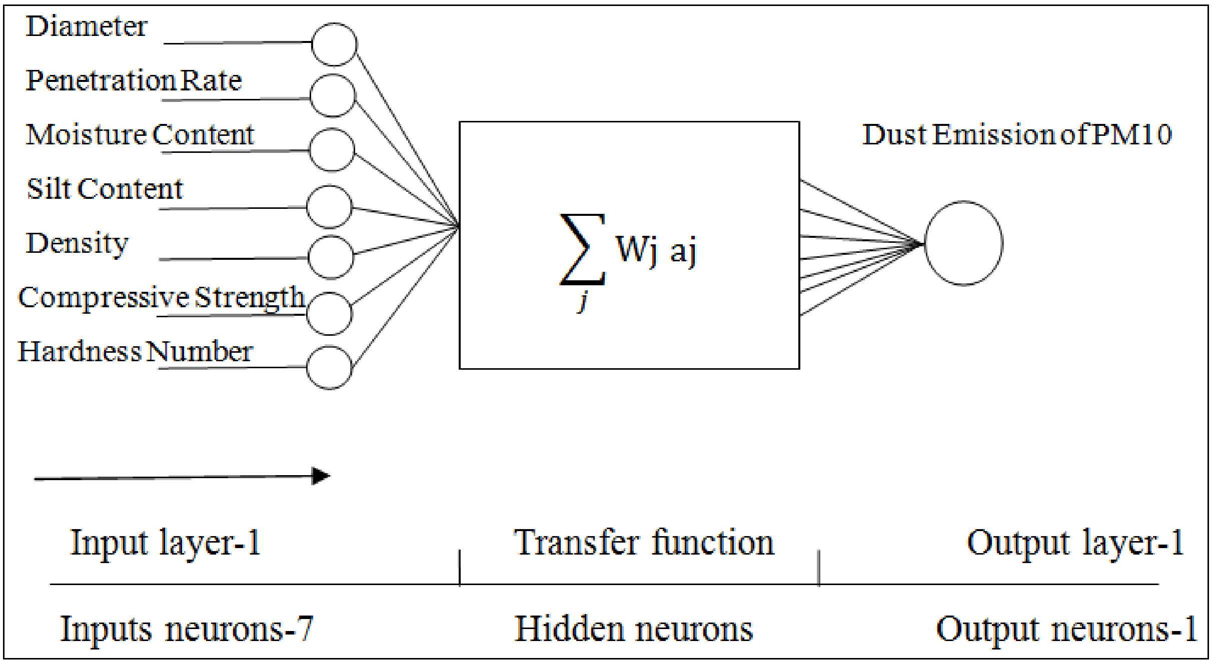

Fig. 3. *A Typical Architecture of Input Variable and Output Variable for Emission Model.*

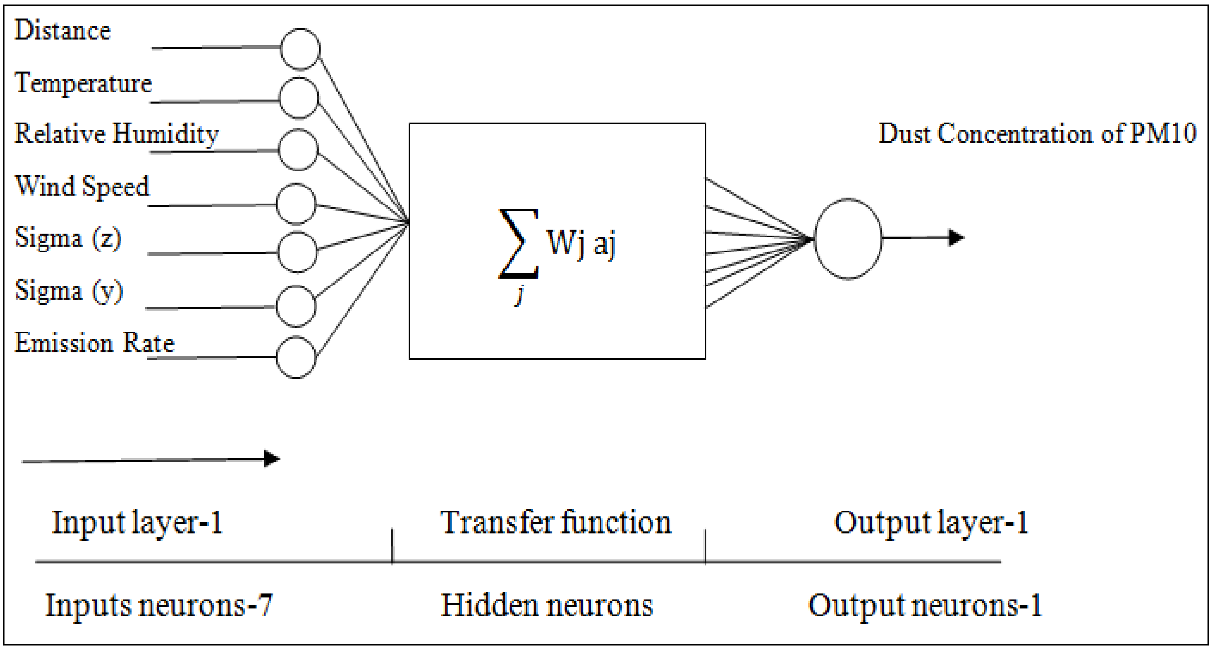

Fig. 4. *A Typical Architecture of Input Variable and Output Variable for Concentration Model.*

Table 7. *Neural Network Architecture and Input Variables for Emission Model.*

Model	Neural network architecture	Input variables
Model 1	7:08:1:1	Diameter, Penetration Rate, Moisture Content, Silt Content, Density, Hardness Number, Compressive Strength

Table 8. *Neural Network Architecture and Input Variables for Various Concentrations Model.*

Model	Neural network architecture	Input Variables
Model 2	7:10:1:1	Distance from source in the direction of wind, Temperature, wind speed, Humidity, emission rate, Dispersion coefficients (σ_z and σ_y)

To obtain minimum Mean root Square Error (MSE) and maximum co-efficient, the 10 hidden neurons and 365 epochs was used. The values obtained for emission model of MSE and correlation co-efficient are 0.0060611 at 365 epochs and 0.96 (Figures 5, 6).

Similarly for concentration model 10 hidden neurons and 1000 epochs was used for to obtain the MSE and co-efficient. The MSE for concentration model was 61.6997 and 0.78 (Figures 7, 8).

The regression co-efficient for predicted and measure values of mine-3 for emission is 0.96, shows excellent correlation. Similarly, the R**2 values for concentration is 0.78 which also shows a good correlation.

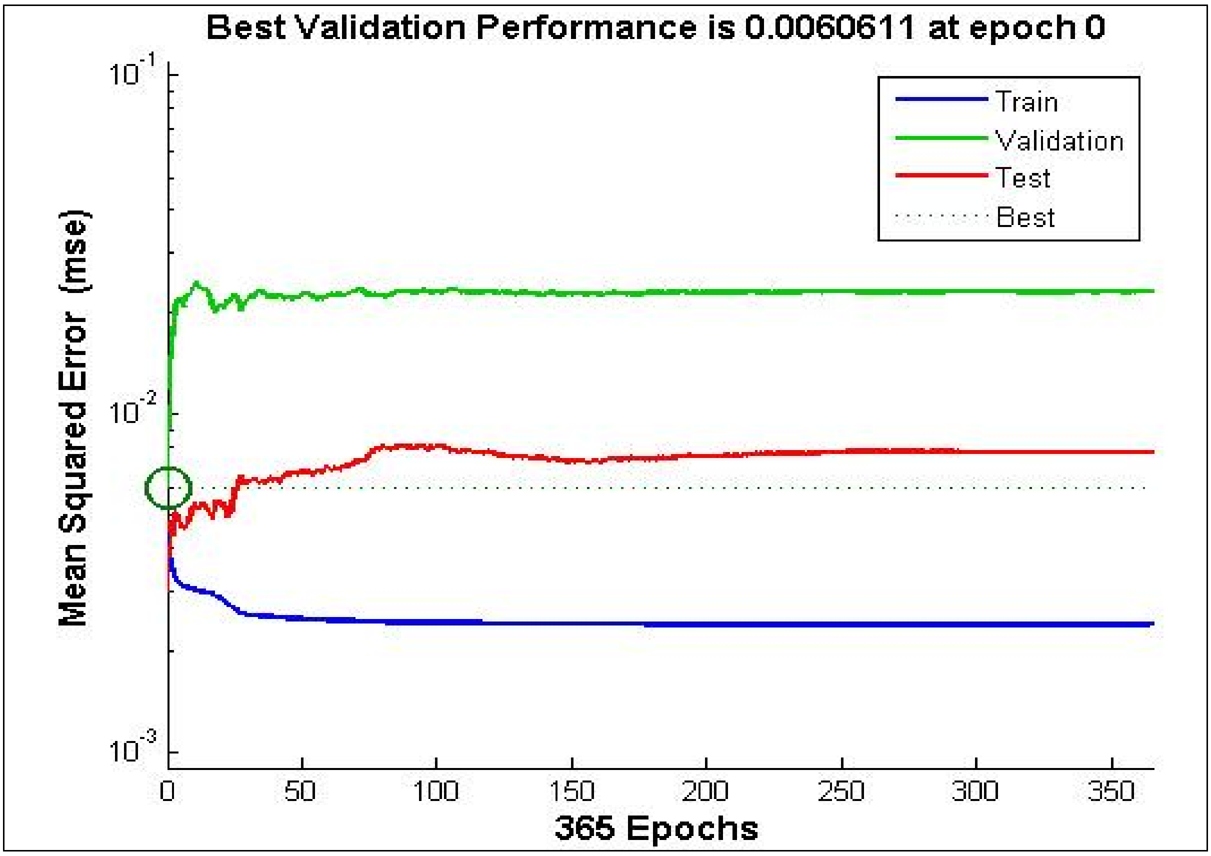

Fig. 5. *Performance of ANN Emission Model for Training and Validation Data for PM10.*

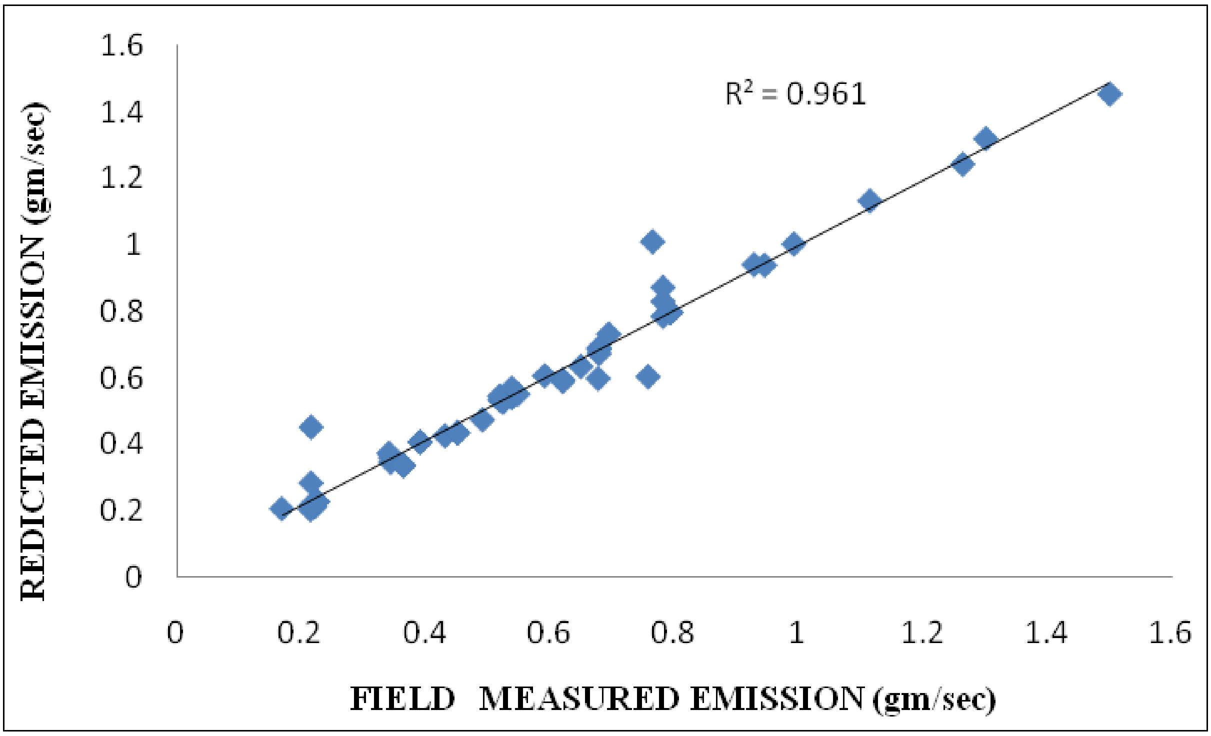

Fig. 6. *Field Measured Values Vs. ANN Predicted Values for Emission.*

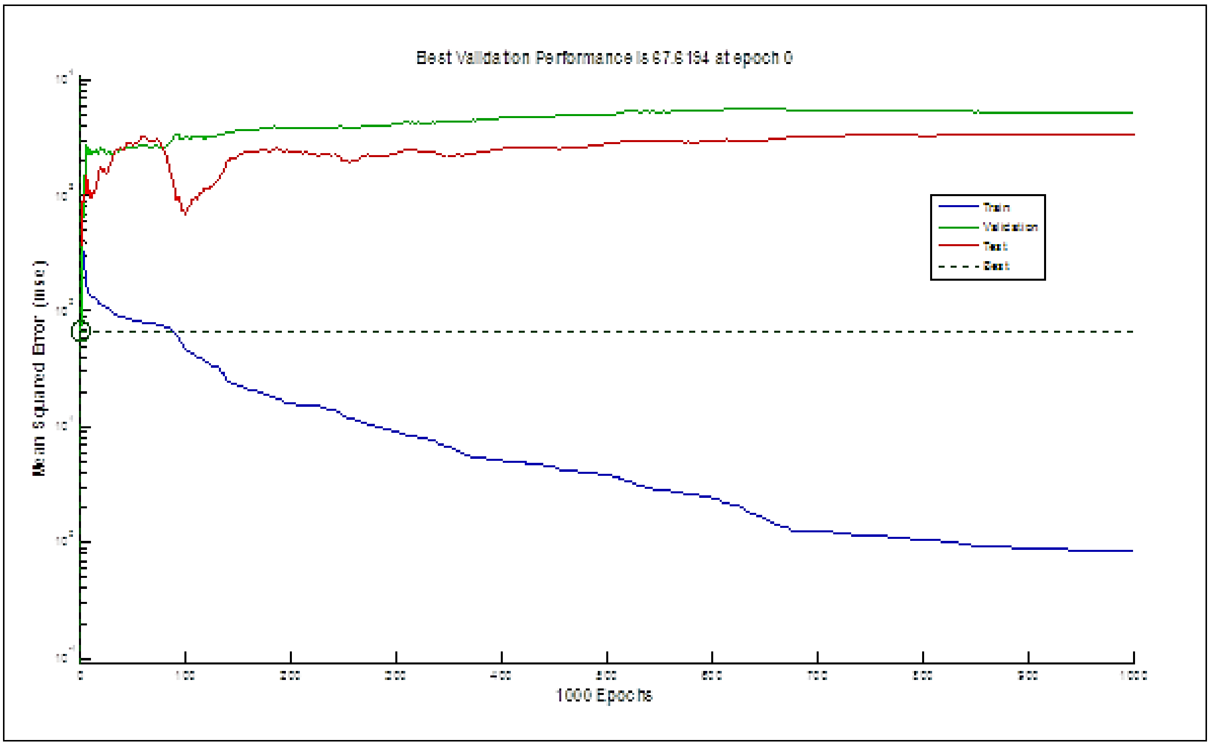

Fig. 7. *Performance of ANN Concentration Model for Training and Validation Data for PM10.*

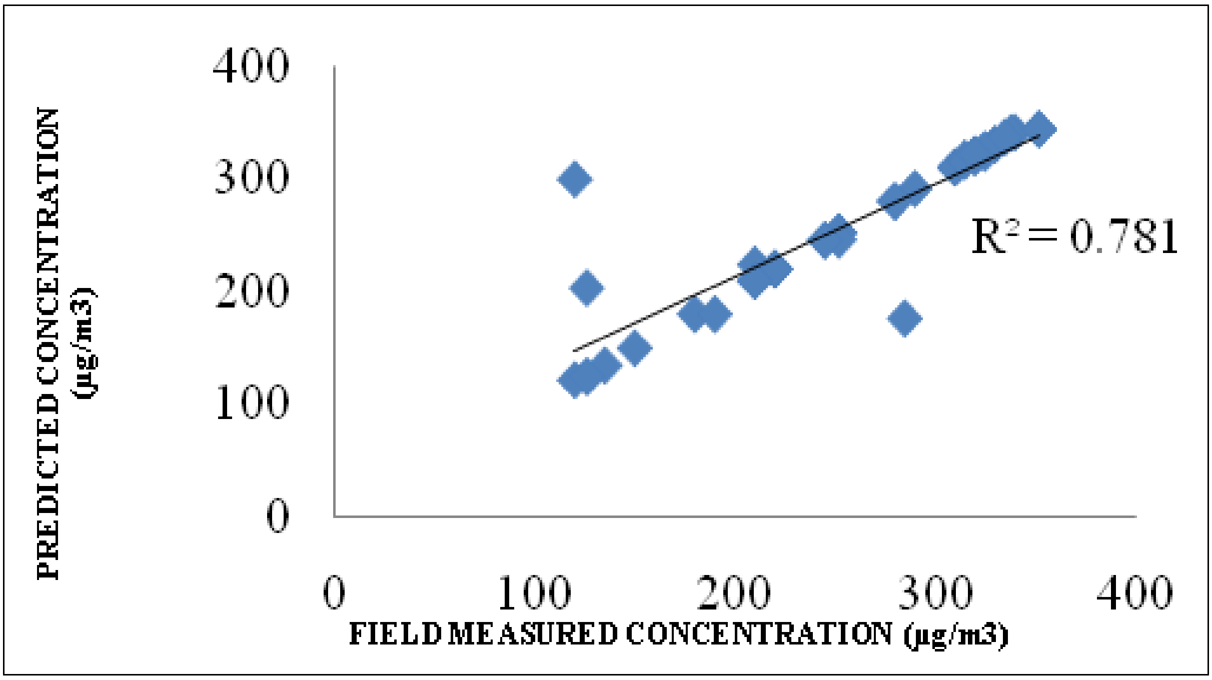

Fig. 8. *Field Measured Values Vs. ANN Predicted Values for Concentration.*

Table 9 shows the several training parameters of neural network for emission model and concentration model in the ANN set up.

Table 9. *Parameters Used in Neural Network for Emission Model and Concentration Model.*

Training parameters	Emission model	Concentration model
Network type	Feed forward back propagation	Feed forward back propagation
Training function	TRAINCGP	TRAINCGP
Adaptive learning function	LEARNGDM	LEARNGDM
Performance function	MSE	MSE
Number of layers	3	3
Number neurons in hidden layer-1	10	10
Transfer function in hidden layer	LOGSIG	LOGSIG
Transfer function in output layer	TANSIG	TANSIG

CONCLUSIONS

Field investigations were carried out in there Indian opencast coal mines. Two mines data was used to develop dust emission and concentration models using ANNs. Third mine data was used to validate the models. The least mean root square error for emission model is 0.0060611 at 365epoch and correlation coefficient was 0.96 for model predicted and the third mine data. Similarly, for concentration MSE is 61.6997 and correlation coefficient is 0.78. Both models show very good correlation between measured and predicted dust levels. Based on this, it can be concluded that the ANN models can be used for prediction of dust emission and concentration of PM10 in open cast coal mines.

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