Modeling the dispersion of dust generated from open pit mining activities

[1]Mithilesh Kumar Rajak, [2]Dr. K. S. Siva Subramanian,
[1]Assistant Professor, [2]Professor
[1]Dept. of Mining Engineering
[1]AMET University, Chennai, India

ABSTRACT

Mining industry is a major source of fugitive dust mostly due to activities which involve handling of large volume of fragmented earth by the HEMMs. The repairable fraction of this dust (size less than 10 microns) is a health hazard, as they have the potential of causing chronic health disorders. Due to this high concentration of repairable dust generated from mining activities, the population directly involved in mining as well as the living in close proximity suffers from a wide variety of respiratory disorders.

If the dust concentration at different location in and around the mining area can be measured then the places with the potential of high concentration build-up can be identified and appropriate protective measures can be taken. This project is a step in that direction.

In this project, the concentrations PM_{10} particles generated from a hypothetical opencast mine having seven dust generation sources has been modeled within an area having a radius of 10 kilometers. The 24-h average concentrations of the PM_{10} particles within the area has been modeled using the AERMOD modeling package and the corresponding concentration plots of the area is plotted. Further analysis of the plots has been done to find the point having maximum concentration of dust.

KEYWORDS: ***Fugitive dust, Fragmented earth, HEMMs, Chronic health disorder, Respirable dust, PM_{10}, AERMOD.***

INTRODUCTION

Turner worked extensively in the field of dust dispersion modeling. By working extensively on the subject, the author estimated the atmospheric dispersion coefficients as a function of downwind distance from the source (Fig. 2.1 (a) and (b)).The results obtained are still widely used for finding the concentration of dust at a particular distance in an atmosphere of particular stability class.[1]

Chaulya studied the quality of air in the opencast mining projects of Lakhanpur area of Ib valley coalfields, Orissa. The study was conducted for 1 full year and the 24-h average concentration of the total suspended particulate (TSP) matter, respirable particulate matter (PM_{10}), sulphur dioxide and oxides of nitrogen (NO_X) were measured. The author developed a relationship between TSP and other pollutants based on linear regression to estimate the concentration of other pollutants based on the knowledge of TSP concentration. In residential areas (buffer zone) sampling and analysis was done bi-monthly and in industrial areas (core zone/mining area) it was done six times a month from September 1998 to August 1999.[2]

Chakraborty et al. carried out a detailed study to predict the emission rates of various mining activities in opencast mines. Seven different coal mines and three iron mines were selected by them based on different parameters like geographical location, accessibility, working conditions etc. to study the emission rates. 12 empirical formulae were developed to estimate the $NO_x$and SO_2 emission rates for different opencast mining activities. Results were validated at the Rajpura opencast mine and the data obtained were found to be of good accuracy ranging from 77.2% to 80.4%.[3]

Ghose and Majee during the study successfully quantified the amount of dust generated from various opencast mining projects. The assessment carried out by the authors involved usage of emission factor data for the quantification of the amount of dust generated. The results obtained showed that wind erosion and coal handling activities are the major sources of dust in opencast mining projects which contributes around 7.8 tons every year. The authors also showed that the heavy mechanization of the opencast mines, under high productivity demands, is the major source of air pollution in those mines. The emission factor suggested in this work could be used for the accurate estimation of dust generated by various activities in an opencast mining project.[4]

Trivedi et al. studied the dust dispersion in an opencast project in the Western Coalfields, India, and modeled the dispersion using Fugitive Dust Model. The results obtained showed that the contribution of various mining activities in an opencast project to the overall dust emission was negligible beyond a certain distance of around 500m. The results obtained were validated and found to have a good accuracy range of around 68%-92%. The authors also suggested various methods for the control and mitigation of the dust generated by the opencast mining activities.[5]

DISPERSION MODELING

Plume Rise essentially involves four phases;
Initial Phase is very important as the pollutant concentration in the area is determined by theheight to which the plume rise occurs. Consequently the ground level concentration getsreduced. The height of rise will depend on:-

a) The emission temperature,
b) The cross-sectional area of the stack,
c) The velocity of the emission,
d) The horizontal wind speed, and
e) The vertical temperature gradient.

For a given set of these conditions the plume will rise to some height (Δh). The height of thestack plus the plume rise (Δh) is called effective stack height

$H=h_s+\Delta h$

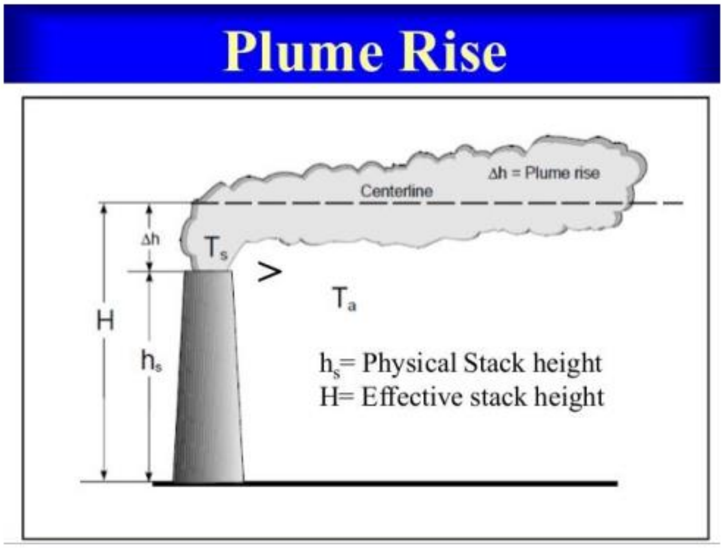


Figure 1 Stack Height and the Plume Rise in a chimney (Jahagirdar, 2013)

For the measurement of plume rise there are two main equations[6]:

Holland Plume Rise (Schnell, 1999)

$$\Delta h = \frac{V_s.D}{u}\left(1.5 + 2.68 \times 10^{-3}.P.D.\frac{(T_s - T_a)}{T_s}\right) \ldots\ldots\ldots\ldots\ldots (3.1)$$

Δh= Plume Rise, in meters.

V_s= Stack exit Velocity, m/s.

D= Stack Diameter, meters.

u= wind speed, m/s.

P= Pressure, mBars.

T_s= Stack Gas Temperature, in Kelvin.

T_a= Atmospheric Temperature, in Kelvin.

BRIGG (1969) PLUME RISE

This is the standard plume rise model used in most EPA air dispersion models.[7] Logic Diagram for using the Brigg's equations to obtain the plume rise trajectory of bent-overbuoyant plumes is presented in Figure 1.

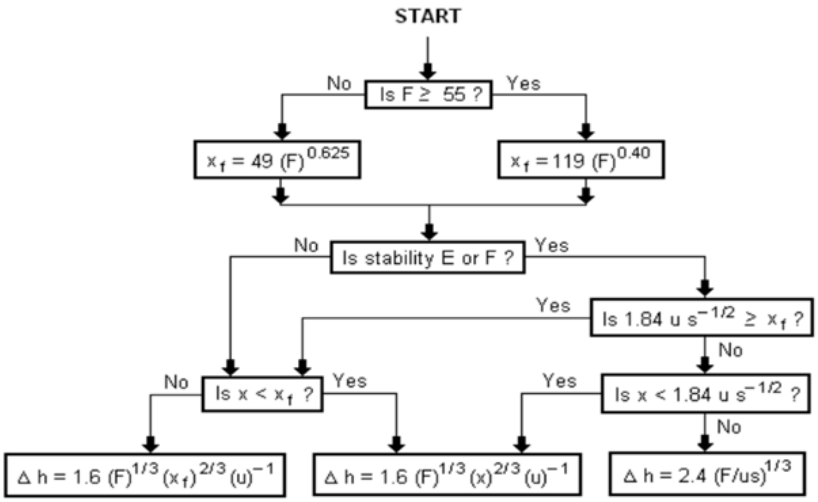


Figure 2 Logic Diagram of Brigg's Equations (Source:-Beychok, 2010)

Δh= plume rise in meters
F= Buoyancy Factor, in m^4/s^3
x= downwind distance from plume source, in meters
x_f= downwind distance from plume source to
point of maximum plume rise, in meters
u= wind speed at actual stack height, in m/s
s= stability parameter, in s^{-2}

GAUSSIAN PLUME MODEL

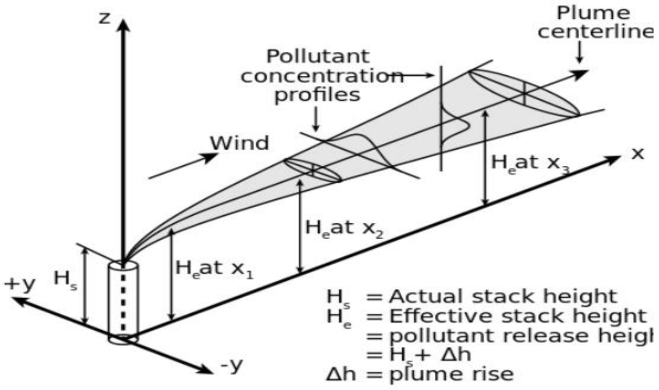


Figure2 Details of the Gaussian Plume Model (ELTE Prompt Portal, 2012)

Commented [I1]: **Figure** should be numbered consecutively in Arabic numerals (1, 2, 3, …) and bear a brief title at the below in sentence case, bold face, Centered and font size 10.

The gas stream, also called as plume, rises from the stack well above the top end of the stack/chimney (Fig. 3.3). Such gas plumes generally rise a considerable distance above the stack due to high temperature and large velocity of the gases.[8]

Using the Gaussian Plume Model (Equation 3.2), we can calculate the air pollutant concentration at any point along the direction of air flow.

$$C = \frac{Q}{u} \cdot \frac{1}{2\pi\sigma_z\sigma_y} \cdot e^{-\left[\left(\frac{y^2}{2\sigma_y^2}\right)\right]} \cdot e^{-\left[\left(\frac{(z-H)^2}{2\sigma_z^2}\right)\right]} \ldots\ldots\ldots\ldots\ldots (3.2)$$

C= Concentration of the air pollutant, in the plume, kg/m^3

Q= emission rate of pollutant, kg/s.

u= average wind velocity, m/s.

y, z= distances from the center line of the plume, m.

σ_y, σ_z = horizontal and vertical dispersion coefficients.

H= effective stack height, m.

ATMOSPHERIC STABILITY

Atmospheric Stability is defined in terms of the tendency of a parcel of air to move upward or downward after it has been displaced vertically by a small amount.[9] Essentially, unstable atmospheres of stability class A tend to develop vertical updrafts which increase boundary layer turbulence intensity.[10] Stable atmospheres (Stability Class F) tend to suppress vertical updrafts and reduce turbulence intensity.[11] Since it is difficult to measure turbulence intensity directly, correlations are sought to indicate stability class as a function of readily available and measurable variables.

The earliest classification scheme is attributed to Pasquill[8], which is summarized in the Table 2.1. This simply requires an estimate of solar radiation and wind speed. It has been shown to produce inconsistent classifications in comparison to other classifications and was thus improved upon by Pasquill[12] by comparing atmospheric stability classes with Richardson Number and ambient temperature changes.

Richardson No.:- It is the ratio of vertical temperature gradient to the squared vertical gradient of wind speed which is given by[13]

$$R_i = \frac{\left[\frac{T(z_1)-T(z_2)}{z_1-z_2}\right]}{\left[\frac{u(z_1)-u(z_2)}{z_1-z_2}\right]^2}$$

R_i = Richardson Number

$T(z_1)$ = Temperature at height Z_1

$T(z_2)$ = Temperature at height Z_2

$u(z_1)$ =Wind velocity at a height Z_1

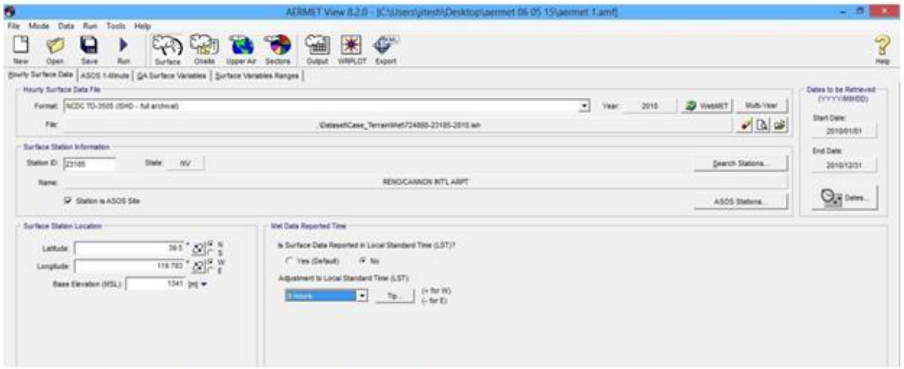
$u(z_2)$ =Wind velocity at height Z_2

z_1, z_2 = Heights at points 1 and 2

AERMET

At first the AERMET results were generated, using the hourly surface data and the upper air data and these data based on wind rose diagrams were further used in the modeling of the dispersion of dust in the mining area.[14]

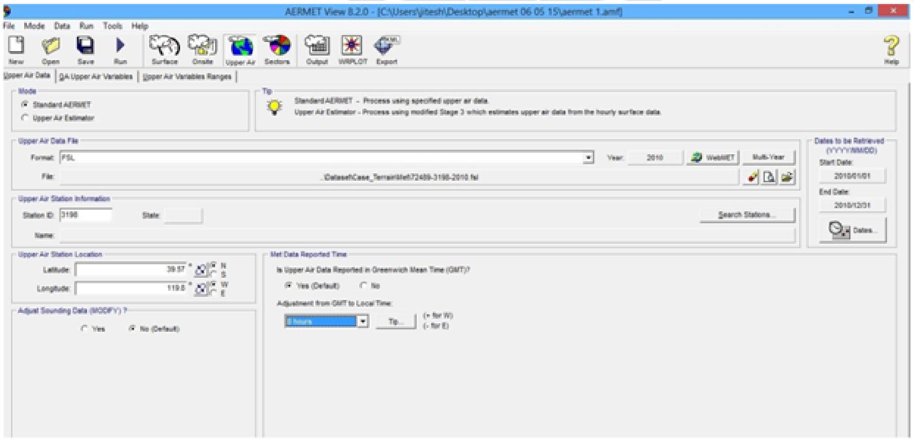
The hourly surface data for one year, in .ish format, was given as input and the location, the local standard time and the base elevation of the point where the data are taken were entered. The point was located at 39.5o N and 119.783o W, the base elevation of the point was taken as 1341 meters, and the local standard time was adjusted to 8 hours ahead of Greenwich Mean Time



Format: NCDC TD-3505 (ISHD - full archival)
Year: 2010
Station ID: 23185
State: NV
Name: RENO/CANNON INTL ARPT
☑ Station is ASOS Site
Latitude: 39.5 ° N
Longitude: 119.783 ° W
Base Elevation (MSL): 1341 [m]
Is Surface Data Reported in Local Standard Time (LST)? ○ Yes (Default) ● No
Adjustment to Local Standard Time (LST): 8 hours
Start Date: 2010/01/01
End Date: 2010/12/31

Figure 3 Details of the input data in AERMET (Hourly Surface Data)

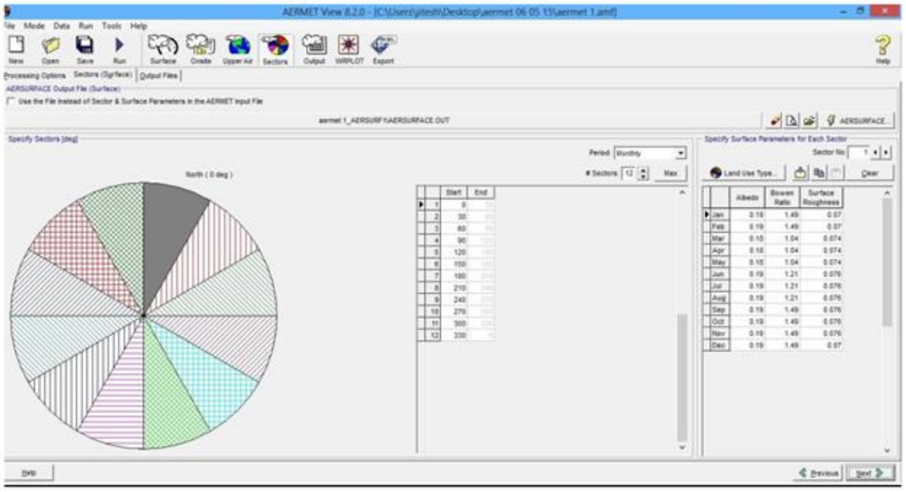
The Upper Air data for one year, in .fsl format, was then given as input and the location, the local standard time and anemometric height was specified.[15] The anemometer was located at 39.57o N and 119.8oW, the height of the anemometer was taken as 33 feet above ground, and the local standard time was adjusted to 8 hours ahead of Greenwich Mean Time (GMT).



Mode: ● Standard AERMET ○ Upper Air Estimator
Standard AERMET - Process using specified upper air data.
Upper Air Estimator - Process using modified Stage 3 which estimates upper air data from the hourly surface data.
Format: FSL
Year: 2010
Station ID: 3198
Latitude: 39.57 ° N
Longitude: 119.8 ° W
Adjust Sounding Data (MODIFY)? ○ Yes ● No (Default)
Is Upper Air Data Reported in Greenwich Mean Time (GMT)? ● Yes (Default) ○ No
Adjustment from GMT to Local Time: 8 hours
Start Date: 2010/01/01
End Date: 2010/12/31

Figure 4 Details of the input data in AERMET (Upper Air Data)

Commented [I2]: **Figure** should be numbered consecutively in Arabic numerals (1, 2, 3, …) and bear a brief title at the below in sentence case, bold face, Centered and font size 10.



aermet 1_AERSURF1\AERSURFACE.OUT

Period: Monthly

Sectors: 12

Sector No: 1

	Start	End
1	0	[illegible]
2	30	[illegible]
3	60	[illegible]
4	90	[illegible]
5	120	[illegible]
6	150	[illegible]
7	180	[illegible]
8	210	[illegible]
9	240	[illegible]
10	270	[illegible]
11	300	[illegible]
12	330	[illegible]

	Albedo	Bowen Ratio	Surface Roughness
Jan	0.19	1.49	0.07
Feb	0.19	1.49	0.07
Mar	0.18	1.04	0.074
Apr	0.18	1.04	0.074
May	0.18	1.04	0.074
Jun	0.19	1.21	0.076
Jul	0.19	1.21	0.076
Aug	0.19	1.21	0.076
Sep	0.19	1.49	0.076
Oct	0.19	1.49	0.076
Nov	0.19	1.49	0.076
Dec	0.19	1.49	0.07

Figure 5 Area is divided into 12 sectors.

Then the data entered was processed using AERMET and two processed files were generated, the preprocessed surface file (.SFC) and the preprocessed profile file (.PFL) after which the wind rose diagrams were generated.

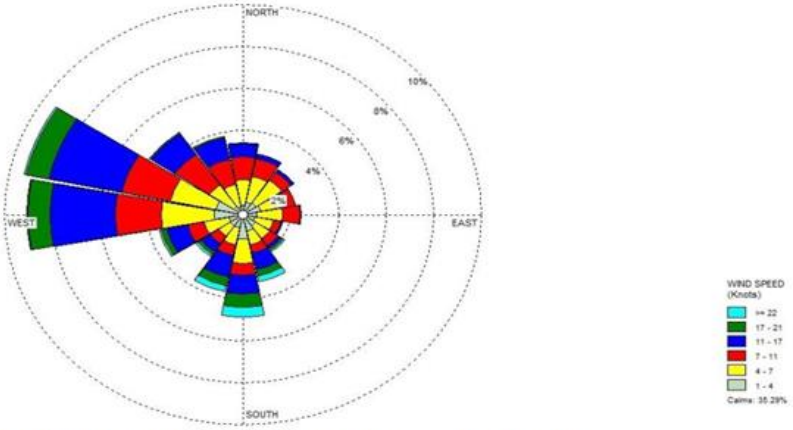


Figure 6 Wind Rose Diagram of the Pre-Processed Surface file.

AERMOD

After the results were processed in AERMET it was used in the AERMOD software to model the dispersion of dust. A Universal Transverse Mercator (UTM) projection was used with WGS84 datum. The UTM zone was taken as 12 N. The centre of the modeling area was taken as the reference point, with an X - coordinate of 523675 m and Y- coordinate of 3521929 m. The radius of the modeling area was taken as 10 kilometers from the centre and terrain height was specified as “elevated”.

In this project only PM_{10} emissions were taken into consideration. The 24-h average concentration of the PM_{10} was measured. The mine sources file generated in an excel sheet containing source type, x and y coordinates of their locations, their base elevations and the release height was given as input.

Then as a seventh source a haul road (which is taken as a line volume source) was created specifying various parameters as follows:-

Vehicle height (VH) = 7.62 m
Factor = 1.7
Plume height (PH) = 12.95 m (PH= factor * VH)
Release height (RH) = 6.48 m (RH = 0.5 * PH)
Initial sigma Z= 6.03 m (Z = PH/2.15)
Lane type = two lane
Road width = 12 m
Plume width = 18 m (PW = RW + 6m)
Emission rate = 19.53 g/s

Table1: Details of the boundary data entered

Point	Coordinates
A	(522173.2, 3522567)
B	(522016.8, 3521593)
C	(522074.2,3521119)
D	(523423.9,3520452)
E	(524492.3,3520665)
F	(525065.5,3521280)
G	(525023.8,3522797)
H	(523960.7,3522990)
I	(522407.7, 3522885)

Table2: Details of the 3-tier grid system created

Tier	Distance From Center(m)	Tier Spacing(m)
1	2500	250
2	5000	500
3	10000	1000

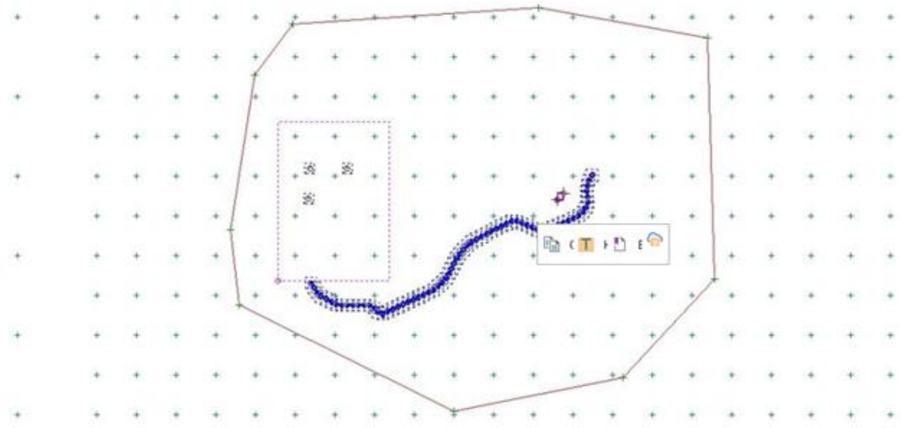


Figure 7 Details of the result after entering the data.

Now the terrain data file which is a Digital Elevation Model (DEM) of the Rosemont Copper Mine was imported. As all the data to be entered have been entered, the mine scenario appeared on the screen as shown in Figure below. The file was ready to be processed to model the dispersionand find the maximum concentration in the area.

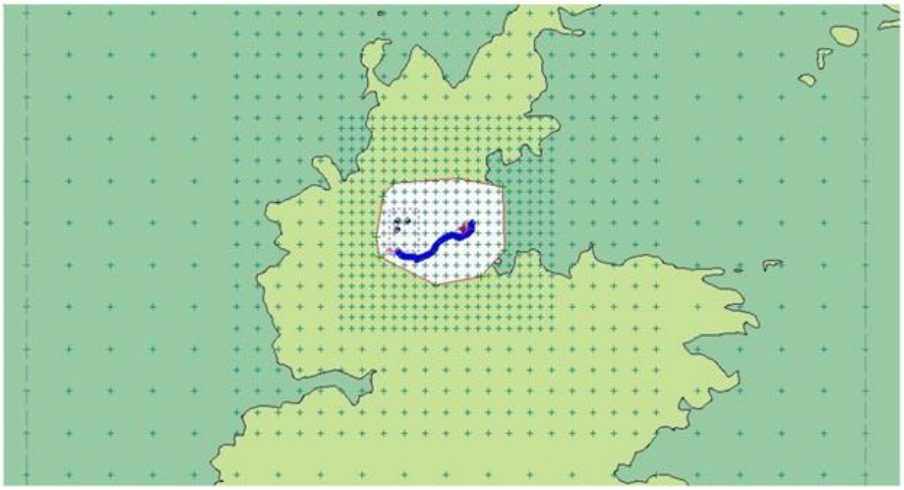
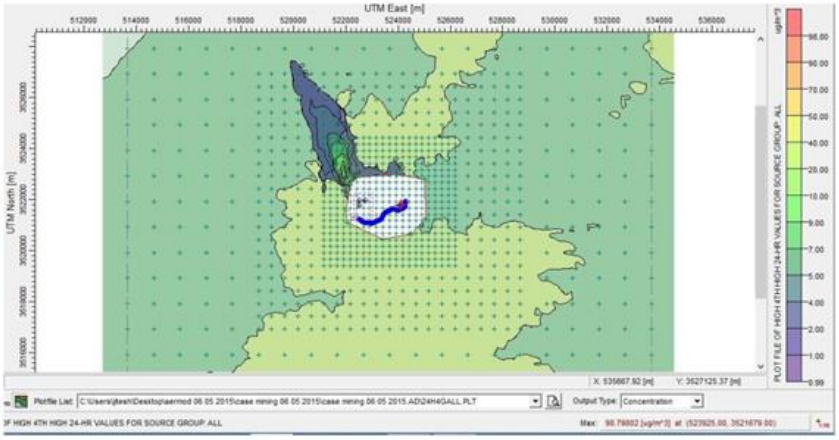


Figure8 Details of the result after entering the terrain DEM file.

RESULT

After all the required data was entered, the data were processed. The result obtained appeared as in the figure. The maximum dust concentration in the area was found to be 98.79802µg/m3; at a location having coordinates (5239925.00, 3521679.00).



X: 535667.92 [m] Y: 3527125.37 [m]

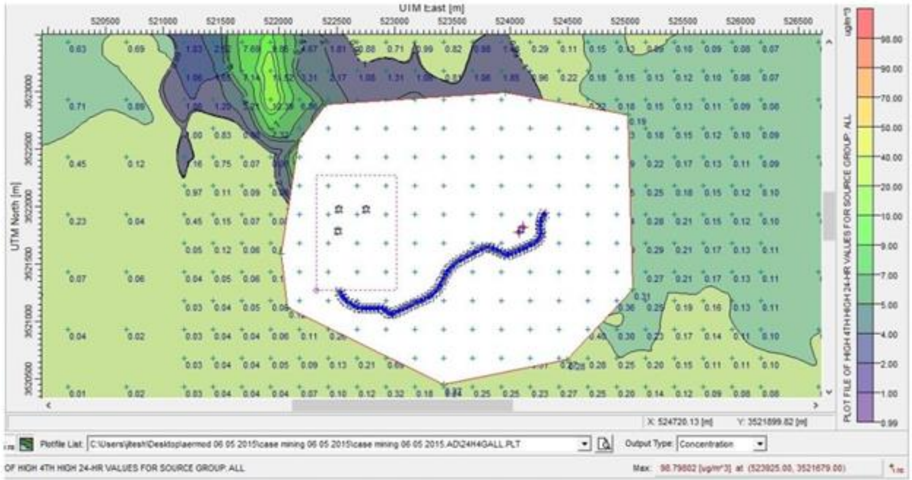
Plotfile List: C:\Users\jitesh\Desktop\aermod 06 05 2015\case mining 06 05 2015\case mining 06 05 2015.AD\24H4GALL.PLT

Output Type: Concentration

OF HIGH 4TH HIGH 24-HR VALUES FOR SOURCE GROUP: ALL

Max: 98.79802 [ug/m^3] at (523925.00, 3521679.00)

Figure 9 Result after processing (showing contours).



X: 524720.13 [m] Y: 3521899.82 [m]

Plotfile List: C:\Users\jitesh\Desktop\aermod 06 05 2015\case mining 06 05 2015\case mining 06 05 2015.AD\24H4GALL.PLT

Output Type: Concentration

OF HIGH 4TH HIGH 24-HR VALUES FOR SOURCE GROUP: ALL

Max: 98.79802 [ug/m^3] at (523925.00, 3521679.00)

Figure10 Details of the result (Showing grid-wise maximum concentration)

REFERENCES

1. Afshar, H., and Delavar, M.R., "A GIS based air pollution Modeling in Tehran", Environmental informatics archives, Vol-5 (2007), pp: 557-566
2. Airborne Dust Sources in a Mining Project, 1983, New South Wales (NSW) State Pollution Control Commission

3. Boorse, D. F., and Wright, R.T., 2011, Environmental science toward a sustainable future, Eleventh edition
4. Briggs, G.A., 1969,"Plume Rise", USAEC Critical Review Series,
5. Chakraborty, M.K.,Ahmad, M., Singh, R.S., Pal, D., Bandopadhyay, C., and Chaulya, S.K., 2002, "Determination of the emission rate from various opencast mining operations, Environmental Modeling & Software", Vol. 17, pp: 467–480
6. Chaulya, S.K., 1999, "Air quality status of an open pit mining area in India", Environmental Monitoring and Assessment, Vol-105, pp: 369–389
7. Ghose, M.K. and Majee, S.R., 2001, "Air pollution caused by opencast mining and its abatement measures in India", Journal of Environmental Management, Vol- 63, pp: 193–202
8. Gifford, F.A., 1960, "Atmospheric Dispersion Calculations using Generalized Gaussian Plume Model", Nuclear Safety, 2, 2, pp: 56-59, 67-68.
9. Kar, S., and Mukherjee, P., 2012, " Studies on Interrelations among SO_2, NO_2 and PM_{10} concentrations and their predictions in Ambient Air in Kolkata", Open Journal of Air Pollution, pp: 42-50
10. Khan, A., Azam, M., Imran S., Thomas B., Hussain M., Said, R., Khan, R., Rahman, N., "Source Apportionment and Characterization of Particulate Matter (PM10) in Urban Environment of Lahore", Aerosol and Air Quality Research, 14: 1851–1861, 2014,
11. Kumari, S., Kumar,R., Mishra, K.K., Pandey, J.K., Nair,G. and Bandopadhyay, A.K., 1995, "Determination of quartz and its abundance in respirable airborne dust in both coal and metal mines in India", Procedia engineering , Vol-26 , pp: 1810-1819
12. Mukherjee, S.K. and Singh, M.M., 1984, "New techniques for spraying dust", Coal Age June, pp: 54-56
13. Pasquill, F. 1961, "The estimation of Dispersion of Windborne Material", Meteorol. Mag., 90, 1063, pp: 33-49.
14. Schnelle, K.B. and Dey, P.B., 1999, Atmospheric Dispersion Modeling Compliance Guide, McGraw-Hill.
15. Turner, D.B., 1971, "Workbook of Atmospheric Dispersion Coefficients", pp: 8-10