Intern. J. Fuzzy Mathematical Archive
Vol. 9, No. 2, 2015, 217-233
ISSN: 2320 –3242 (P), 2320 –3250 (online)
Published on 8 October 2015
www.researchmathsci.org

International Journal of
Fuzzy Mathematical
Archive

Computed Aided Air Pollution Dispersion Modeling in and Around Mining and its Allied Industrial Complexes

***M.Sundararajan* [1] and *R.Judith Kiruba* [2]**

[1]Senior Principal Scientist & Head, Placer Mining (CIMFR)
Cm Professor in Engg. Mathematics (AcSIR)
CSIR-Central Institute of Mining and Fuel Research, Barwa Road
Dhanbad-826 015, Jharkhand.
[2]T.B.M.L. College, Porayar-609 307, Tamil Nadu

Received 1 September 2015; accepted 1 October 2015

***Abstract*.** In the present paper, using a modified computer aided Gaussian dispersion model, simulation of SPM and SO_2 has been exercised in and around the coal washery complexes, which are situated at the banks of Damodar River, which flowing through Dhanbad District of Jharkhand State. The isopleths of air quality parameters, SPM and SO_2 have been presented in order to visualize the dispersion pattern of the air pollutants in and around coal washery complexes. The presented model will be a pioneer work for the environmental researchers, engineers, policy makers and protection agencies to assess the impact of industrial activities in coal mining areason the ambient air quality and valuable receptors such as civil structures, flora and fauna.

Keywords: Pollution dispersion modeling, allied industrial complexes

AMS Mathematics Subject Classification (2010):

1. Introduction

The impacts of air pollution, in particular the suspended particulate maters are considerably severe in and around a coal washery complex. The dust is generated significantly due to different operational units such as screening, crushing, loading & unloading, exposed piles and stock yards, thermal dryers and the dropping points of conveyer belts etc. The particulate maters generated during its operations are being transported by wind in downwind direction and disperse both horizontally and vertically. Further the pollutants have an adverse impact on the buildings, plants and other valuable receptors [1]. As a result, the whole eco-system is disturbed and the fertility status of the soil around the coal washery complex is significantly changes with unpleasant impacts [2]. Therefore it is very much warranted to estimate the emission of air quality from different sources of coal washery complexes using suitable statistical approach. Further the air quality in and around coal washery complexes has to be predicted using an appropriate air quality dispersion model, developed for multi-sources like elevated point source, area source, ground level point source and line source taking the terrain elevation factor and the effect of temperature variance into account.

Much attention has been paid to develop mathematical models for simulating the suitable flow-sheets on the basis of the characterization the coal received from the nearby mines for preparing coals for the indented use in order to increase the production of coal with intended to meet the fast growing demand of the energy. Unfortunately less focus has been made for simulating the environmental impact due to coal preparation plants. Simulation of environmental scenario in and around coal washery complexes may help the industry in planning and implementing the control strategies for protecting the surrounding from the adverse impact. The present research work contributes towards Environmental Management Plan (EMP) through air pollution impact assessment using computer aided mathematical models.

2. Methodology

Study Domain

Three windows covering the river course have been considered for the present study and the total area of the three study windows is about 196.8 km^2. The location of the study area has been shown in **Fig.1**. The geographical boundary of the study area is 23°35'00" to 23°45'00" N latitude and 86°15'00" to 86°30'00". E longitude. The chosen study window containing seven coal washeries and river stretch of length about 38 km, which has been divided into three sub-windows in order to carry out the study over the impact of coal washeries on the environment using the present models. The river stretch starts from the outfall point of Mahudah Coal Washery to the confluence point of Damodar river and Govai river, which carries the effluents of Bhojudih Coal Washery and Santhaldih Thermal Power Station to the Damodar. The river stretch, which has been considered for the present study is just, located at the bottom of the Jhariah coalfields in southern side.

Mathematical Models

When pollutants are emitted into the atmosphere, they are immediately diluted, transported and mixed with the surrounding air. The role of air quality modeling is to represent these processes mathematically.Dispersion models are formulated from the fundamental differential equations governing the concentrations of pollutant species. Dispersion models are more appropriate for the prediction of air quality because the models consider the point-by-point transport, dispersion, generation and removal of pollutant species and provide for spatial and temporal variation of those processes.The first step is to construct the basic mathematical equations upon which the models are founded. Consider the small control volume. If we assume the control volume can occur by transport and mass balance for species ‘**j**’ may be expressed as follows [3-5].

$$\frac{\delta}{\delta t}(VC_j) + \frac{\delta}{\delta x}(C_j \bar{u}\, dydz)dx + \frac{\delta}{\delta y}(C_j \bar{u}\, dzdx)dy + \frac{\delta}{\delta z}(C_j \bar{u}\, dxdy)dz$$

$$-\frac{\delta}{\delta x}\left(D_x d_z d_y . \frac{\delta C_j}{\delta x}\right)dx - \frac{\delta}{\delta y}\left(D_y d_z d_x . \frac{\delta C_j}{\delta y}\right)dy - \frac{\delta}{\delta z}\left(D_z d_x d_y . \frac{\delta C_j}{\delta z}\right)dz - Ø_j dxdydz = 0 \quad (1)$$

where **V** = the volume of the control volume (m^3)

$\bar{u}$ = the average cvonvective velocity in the x - direction (m/s)

$\bar{v}$ = the average cvonvectiv e velocity in the y - direction (m/s)

$\mathbf{C_j}$= the concentration of pollutant species (kg/ m^3)

$\mathbf{D_x}$= the turbulent mixing coefficient associated with the x-direction (m^2 /s)

$\bar{w}$ = the average cvonvective velocity in the z - direction (m/s)

D_y= the turbulent mixing coefficient associated with the y-direction (m^2 /s)
D_z= the turbulent mixing coefficient associated with the z-direction (m^2 /s)
$Ø_j$= a local term for the creation or removal of pollutant species j (kg/s/m^3)

$$\frac{\delta C_j}{\delta t}+\frac{\delta}{\delta x}(_j\bar{u}C_j)+\frac{\delta}{\delta y}(\bar{v}C_j+\frac{\delta}{\delta z}(\bar{w}C_j)-\frac{\delta}{\delta x}(D_x.\frac{\delta C_j}{\delta x})-\frac{\delta}{\delta y}(D_y.\frac{\delta C_j}{\delta y})-\frac{\delta}{\delta z}(D_z.\frac{\delta C_j}{\delta z})-Ø_j=0 \quad (2)$$

Now, if we recognize that **V** = **dx dydz**, the above equation can be simplified as follows. Further, if we consider the mixing coefficients, **D_x**, **D_y** and **D_z** to be approximately constants at a given time and location and also if we apply the continuity equation for an incompressible fluid,

$\frac{\delta u}{\delta x}+\frac{\delta v}{\delta y}+\frac{\delta w}{\delta z}=0$, then it reduces to the basic dispersion equation as follows.

$$\frac{\delta C_j}{\delta t}+\bar{u}\frac{\delta C_j}{\delta x}+\bar{v}\frac{\delta C_j}{\delta x}+\bar{w}\frac{\delta C_j}{\delta x}-D_x.\frac{\delta^2 C_j}{\delta x^2}-D_y.\frac{\delta^2 C_j}{\delta y^2})-D_z.\frac{\delta^2 C_j}{\delta z^2})-Ø_j=0 \quad (3)$$

Gaussian models are constructed by application of the following assumptions to the basic dispersion equation.

(a) In steady state condition, it is assumed that $\frac{\delta C_j}{\delta t}=0$, i.e., the concentration of pollutant at a given point P(x,y,z) in space is constant.

(b) It is assumed that the wind speed u is taken as uniform in space and invariant in time, and $\bar{v},\bar{w}=0$

(c) It is assumed that $\bar{u}\frac{\delta C_j}{\delta t} << D_x\frac{\delta^2 C_j}{\delta^2 x}$. when the pollutant is transported in wind direction, i.e., in x-direction, the concentration of pollutant is controlled by convection.

Application of the above assumptions (1) reduces to the following form.

$$\underbrace{\bar{u}\frac{\delta C_j}{\delta x}}_{\text{Convection term}}=\underbrace{D_z\frac{\delta^2 c_j}{\delta z^2}+D_y\frac{\delta^2 c_j}{\delta y^2}}_{\text{Dispersion term}}+\underbrace{\Phi_j}_{\text{Generation/removal term}}=0$$

The above equation consists of a convection term, dispersion terms and generation/removal term. The concentration (**C_j**) at a point (**x**,**y**,**z**) downwind of the source depend upon the concentration of the species by wind transport, the lateral and vertical speed of species by turbulent dispersion, and the generation or removal of the species by chemical reaction. The above second order differential equation may be solved if the following additional assumptions are applied.

(a) The concentration in the **x**,**y** planes follows a Gaussian (normal) distribution in each of the two dimensions.
(b) The pollutant species j is omitted from the source at a uniform rate, **Q_j.**
(c) The generation or removal of species within the flow-field is zero, (i.e., non-creating field).

Applying such assumptions to the above equation, we can get the following equation with polar coordinate system, which is known as Gaussian dispersion model, depicted here by the following equation for a point source.

$$C_j(r,\theta,h) = \frac{Q_j}{2\Pi\hat{u}\,\sigma_y\,\sigma_z} e^{-\frac{1}{2}\left(\frac{r\sin^2\theta}{\sigma_y^2} + \frac{h^2}{\sigma_z^2}\right)} \quad (4)$$

where
- **r** = distance from the point to the origin (m)
- **θ** = angle of the line joining the point and the origin with the positive direction of x-axis (degree)
- **h** = height from the surface (m)
- $\mathbf{C_j}$= concentration of species j at the point (r, θ, h) (g/sec)
- $\mathbf{Q_j}$= emission rate of the species j (g/sec)
- **û** = average wind speed (m/sec)
- $\boldsymbol{\sigma_y}$, $\boldsymbol{\sigma_z}$= Gaussian dispersion coefficients for horizontal and vertical directions

Gaussian Dispersion model is nothing but the normal distributive function of the pollutants along the down wind direction (positive x-axis) and normally distributed along the y-axis having its peak at **y**=0. The Gaussian plume equations have been presented for various types of sources located at the point represented by the polar coordinate system (**r,θ**) where **r** is the distance of the point from the origin and **θ** is the angle of line joining the point and the origin with the positive direction of x-axis.

Elevated point source: For a source elevated a distance H above ground level, the Gaussian plume geometry and the plume equation is presented as follows:

$$Cj(r,\theta,h) = \frac{Q_j}{2\Pi\hat{u}\,\sigma_y\sigma_z} e^{-\frac{1}{2}\left\{\frac{r\sin^2\theta}{\sigma_y^2} + \left[\frac{(h-H)^2}{\sigma_z^2} + \frac{(h+H)^2}{\sigma_z^2}\right]\right\}} \quad (5)$$

where

r = distance from the point to the origin (m)

θ = angle of the line joining the point and the origin with the positive direction of x-axis (degree)

h = height from the surface (m)

$\mathbf{C_j}$ = concentration of species j at the point (x, y, z) (g/sec)

$\mathbf{Q_j}$ = emission rate of the species j (g/sec)

û = average wind speed (m/sec)

H = effective plume height (m)

$\boldsymbol{\sigma_y}$, $\boldsymbol{\sigma_z}$= Gaussian dispersion coefficients for horizontal and vertical directions

In plume geometry of an elevated point source, the plume dispersion is assumed to be begun from the plume centerline. The Gaussian dispersion model for the elevated point source is denoted as C_e for convenient in the present study.

Ground-level point source: For a source at ground level with perfect reflection, the Gaussian plume dispersion and the plume equation is presented as follows:

$$C_j(r,\theta,h) = \frac{Q_j}{\Pi \hat{u}\, \sigma_y\, \sigma_z} e^{-\frac{1}{2}\left(\frac{r\sin^2\theta}{\sigma_y^2} + \frac{h^2}{\sigma_z^2}\right)} \tag{6}$$

where **r**= distance from the point to the origin (m)

θ= angle of the line joining the point and the origin with the positive direction of x-axis (degree)

h = height from the surface (m)

$\mathbf{C}_j$= concentration of species j at the point (r, θ, h) (g/sec)

$\mathbf{Q_j}$ = emission rate of the species j (g/sec)

û = average wind speed (m/sec)

$\boldsymbol{\sigma_y}$,$\boldsymbol{\sigma_z}$= Gaussian dispersion coefficients for horizontal and vertical directions

The Gaussian dispersion model for the ground level point source is denoted as C_g for convenient in the present study

Line source: For a line source the Gaussian plume dispersion and the plume equation is presented as follows:

$$Cj(r,\theta,h) = \frac{2Q_j/L}{\sqrt{2\Pi}\,\hat{u}\,\sigma_z} e^{-\frac{h^2}{2\sigma_z^2}} \tag{7}$$

where **r** = distance from the point to the origin (m)

θ = angle of the line joining the point and the origin with the positive direction of x-axis (degree)

h = height from the surface (m)

$\mathbf{C_j}$ = concentration of species j at the point (x, y, z) (g/sec)

Q = emission rate of the line source per unit length (g/sec)

û = average wing speed (m/sec)

L = Length of the line source (m)

$\boldsymbol{\sigma_z}$= Gaussian dispersion coefficients for vertical directions

The Gaussian dispersion model for the line source is denoted as $\mathbf{C_l}$for convenient in the present study.

Area source: The area source can be assumed as a finite number of point source by dividing into finite number of grids by taking the grid size as small as possible. Each grid is assumed as a point source. Once the emission of the air pollutants per unit area is computed, the emission from each grid can be calculated, as it is directly proportional to the area of the source falls within the grid considered. Here the location of each grid source is assumed as the center of the grid. The Gaussian dispersion model for the area source is denoted as $\mathbf{C_a}$ for convenient in the present study.

Effect of temperature

The temperature varies with respect to the terrain elevation. Such a variation in temperature alters the selection of stability class as the mixing of pollutants in the atmosphere is influenced in reducing the concentration with the increase in temperature. When the mean sea level increases the temperature decreases in a study area with certain fixed boundary that satisfy a certain boundary condition. If $\mathbf{T_r}$is the reference temperature at known mean sea level $\mathbf{M_r}$ then the unknown temperature ($\mathbf{T_x}$) at the known and varying mean sea level ($\mathbf{M_x}$) can be related with the following localized equation to use only within the area, which has the constant temperature at the same mean sea level but at varying locations.

$$T_x = T_r \, e^{k\left[\left(\frac{M_r}{M_x}\right)-1\right]} \tag{8}$$

where **k** is the constant, which can be calculated by taking the average values of **k** calculated for different known values of mean sea level and corresponding temperature at different place in the study area. The temperature has significant influence on the concentration of the air quality. When the temperature increases the air molecules becomes light and has the tendency to go upwards and simultaneously, the plume geometry is being altered by increasing the volume. As a result, the concentration is diluted significantly. It is very complex to estimate the volume of the plume geometry. However, mathematically we can correlate the diluted concentration with respect the increase or decrease in temperature. Let c(r, T_r) be the concentration when the temperature was T_r at the reference point and let c(x, T_r) be the predicted concentration after the traveling to the point, x by the control volume in the downwind direction with the same temperature T_r. If the temperature changes with respect to the mean sea level variation after traveling to the point, x into T_x, then the concentration C(x, T_x) may be estimated as

$$C(x, T_x) = C(r, T_r) \; e^{\mu\left[\left(\frac{T_r}{T_x}\right)-1\right]} \tag{9}$$

where μ is the empirical coefficient and this can be estimated through the experiments conducted at different locations of the study area along the wind axis and then substituting the known temperatures, concentrations, and the average value of $\boldsymbol{\mu}$can be calculated. The exponential value in the second part of the above equation is known as dilution factor of the concentration due to increase in temperature. For example, Assuming the temperature $\mathbf{T}_r=47^o$ at the point located at 300ft mean sea level, the temperature profile has been plotted for the mean sea level varies from 200 to 400 using the empirical model developed for interpolating the temperature for unknown locations within a local study area.

Effect of terrain elevation

In the hilly or elevated terrain, the plume axis will not be a straight line. As the wind follows the terrain elevation while blowing, the plume axis will be parallel to the terrain surface. The terrain elevation has the impact on the dispersion phenomena of the pollutants in the atmosphere. The variation in transport distance alters the stability class and dispersion coefficients. When the wind blows in particular direction, generally the wind path of volumetric element of the air is parallel to the topographical elevation. When the mean sea level from the particular point on the terrain increases, the temperature decreases. Therefore, there is a need to incorporate these parameters while carrying out the study over the dispersion of air pollutants in and around the industrial complex located in the terrain with significantly varying elevations.

The terrain PQRST in the wind direction has varying elevation. The wind path is just parallel to the terrain PQRST. Since the ground level air quality is usually predicted at 6 m height from the ground level. The wind path at 6 m from the ground level may be assumed approximately equal to the length of PQRST. Therefore, the actual distance traveled by the pollutant species from $\mathbf{x_o}$ to $\mathbf{x_n}$in the wind direction may be calculated using the following formula.

$$d\{(x_o,y),(x_n,y)\}=\sum_{i=1}^{n}\sqrt{(x_i-x_{i-1})^2+(z_i-z_{i-1})^2} \quad (10)$$

where $(\mathbf{x_o,y})$ = reference point

$(\mathbf{x_n,y})$ = point for which the air quality to be predicted

$\mathbf{Z}$ = the vertical axis representing the mean sea level

$\mathbf{d}\{(\mathbf{x_o\,,y}), (\mathbf{x_o\,,y})\}$=distance between $\mathbf{x_o}$ and $\mathbf{x_n}$ at **b**

Dispersion coefficients

The present model require information on the values of the dispersion coefficients σ_y and σ_z , and also the variation of these coefficients with atmospheric stability classes, wind speed, wind speed and down wind distance. Although many experiments haven made by the researchers to compile different set of σ_y and σ_z as a result of verity of investigations, the dispersion coefficients compiled by Pasquil and Gifford based on their experiment are shown in **fig.2**and are widely used by the environmental engineers. An attempt has been made to develop empirical models for the ground level source for different stability classes according to the meteorological condition of the study area on the basic experimental data compiled by Pasquil and Gifford. The stability classes have been classified as A,B,C,D,E and F. Class A is the most unstable and class F is the most stable. For evaluations, the neutral class-D is most often used. By using the wind directions and wind speed given in wind-rose diagram given in **fig.3** for both summer and winter and the two dimensional analytical geometrical techniques presented in **fig.4** to exclude the ineffective sources of pollutants, the air quality has been predicted.

Computer-Aided Model

The air quality dispersion model is obtained for the multi-industrial source complex, hilly terrain and valle. The model has been derived on the basic concept of Gausian dispersion models discussed above, which was later made more effective by Turner. The sources of the air pollution may be categorised as Groud level point source (**G**), Elevated point source (**E**), Area source (**A**) and Line source (**L**).

$$\mathrm{C(x,y,z)} = i=\sum_{i=1}^{n} I(x_i,y_i)\,\mathrm{J(e,a,g,l)}\,[C_e+C_a+C_g+C_l] \quad (11)$$

In the above equation, the index function takes care to include the source to compute the concentration if it is located in the upwind direction, otherwise it will exclude the impact of the source. Moreover, the index variable **e**,**a**, **g** and **l** of the operator **J** have the value either 1(it the concerned source is present) or 0 (if the concerned source is not present) and the operator **J**(**g**,**e**,**a**,**l**) operates as **J**(**e**,**a**,**g**,**l**) $(\mathbf{C_e}+\mathbf{C_a}+\mathbf{C_g}+\mathbf{C_l}) = \mathbf{e.C_e}+\mathbf{a.C_a}+\mathbf{g.C_g}+\mathbf{l.C_l}$, where $\mathbf{C_e}$, $\mathbf{C_a}$, $\mathbf{C_g}$ and $\mathbf{C_l}$are the Gaussian dispersion models for the respective sources, viz., ground level point source, elevated point source, area source and line source. In the present model, the following influencing parameters and techniques have been incorporated using suitable mathematical tools.

- Sign of the perpendicular distance from source to the normal line of wind axis passing through the prediction point in order to include or exclude the effective and non-effective sources.
- Transport distance of the control volume along the wind direction over the elevated terrain elevation
- Influence of temperature variation on the transport of control volume due to terrain elevation factor
- Support of empirical models correlating the emission factors of the air pollutants from fourteen sources with the emission influencing parameters like moisture content, silt content, wind speed and other major dependent parameters.

The above discussed mathematical models were applied for the prediction of environmental parameters for both water and air environment. The Computer-Aided Gaussian Plume Modeling was carried out using the Pasquill–Gifford coefficients for both horizontal dispersion and vertical dispersion using the plot shown in **Fig.2** [6].

Empirical models for estimating emission factors

The major sources of air pollutants in and around a coal washery complex are coal stockpiles and silos, rotary-breaker and crusher installations, thermal dryers, coal handling and loading areas, conveyer built transfer points, dry-screening operations, dry-cleaning operations, haulage roads and transport roads. Further, the activities concerning the major sources have been identified and listed as follows:(i) Unloading of raw coals, (ii) Loading of clean coals, (iii) Loading of middlings, (iv) Loading of rejects, (v) Transport roads, (vi) Haul road, (vii) Screening plant, (viii) Thermal dryers, (ix) Exposed piles of clean coal, (x) Exposed piles of middlings, (xi) Exposed piles of rejects, (xii) Exposed surface area, (xiii) Rotary crusher and (xiv) Conveyer-belt's dropping points [4]. Empirical models were developed to calculate emission rate of the suspended particulate matters as it is the major problem in the coal washery complexes. The emission of the suspended particulate matters from a source has been assumed the multiplicative effect of the influencing parameters as it is the integrated outcome of the influencing parameters. Therefore, the empirical models have been assumed as the product of exponent of the influencing parameters. Further, the influencing parameters have been taken in the form $\mathbf{u^c}$**,** where **c** is the exponent. If it results into zero emission, zero is assigned to the value of exponent. For example, consider the effect of wind speed on the suspended solids' emission from the source of raw coal piles. It is assumed that the emission is zero if the wind is calm. If we consider the source of the transfer point of conveyer-belt, the emission is assumed to be non-zero when the wind is calm as the conveyer-belt is in motion. Therefore, the factor is taken as $(\mathbf{p}+\mathbf{qu})^c$, where **p**, **q** are linear constants and c is the exponent. If we consider **n** parameters whose influence is in the forms $\mathbf{x^c}$and **m** parameters in the form $(\mathbf{p}+\mathbf{qy})^d$, then we can assume the empirical model for estimating the emission rates from particular source as follows.

$$E = k\, x_1^{c_1}\, x_2^{c_2}\, x_3^{c_3} \ldots x_n^{c_n} . (p_1 + q_1 y_1)^{d_1}\, (p_2 + q_2 y_2)^{d_2} (p_3 + q_3 y_3)^{d_3} \ldots (p_m + q_m y_m)^{d_m} \quad (12)$$

where k is a correction factor. By taking logarithm on both sides, we can get,

$$\log E = \log k + \sum_{i=1}^{n} c_i \log x_j + \sum_{j=1}^{m} d_j \log(p_j + q_j y_j) \quad (13)$$

In above system of (**m**+**n**+1) non-homogeneous linear equations, for different values of $\mathbf{x_i}$and ($\mathbf{p_j}$+$\mathbf{q_j y_j}$), the non-trivial solution for logk, $\mathbf{c_j}$ and $\mathbf{d_j}$can be found using regression method.

The emission rates of different washery activities and significant sources were estimated based on modified Pasquill and Gifford formula for ground level sources through field experiments in order to estimate the values of the empirical coefficient and unknown exponents for different sources and activities and the formula is

$$Q = \Pi u \sigma_y \sigma_z C_{x,o} \quad (14)$$

where $\mathbf{C_{X,O}}$ refers to difference between the downwind and upwind concentrations of the pollutant species (g/ m^3), **Q** is emission rate of the pollutant species (g/s), **u** is average wind speed (m/s), and $\boldsymbol{\sigma_y}$ and $\boldsymbol{\sigma_z}$ are respectively the horizontal and vertical dispersion coefficients, compiled in functions of downwind distance x(m).

In case of elevated point sources, the sampler was kept approximately at the same height and the above formula was used to estimate the emission rate. As the sampler is kept very near to the source, the error in the calculation of emission rate using this formula would be negligible. Further, the same formula was used to measure the emission rate from the other sources like line and area assuming the unit length or unit area of the source as a point source since the source is the union of finite number of such parts. In fact, the method to estimate $\mathbf{C_{X,O}}$ in order to exclude the effect of upwind source on the considered source is not appropriate, as the concentration measured at the upwind direction will be reduced significantly while it disperses towards the downwind direction. The application of difference between the downwind and upwind concentration in the emission formula to estimate the emission rate of the source will not give accurate result. A studies have reported a distance scheme to eliminate the concentration from upwind source using the following formula [7,8]:

$$C_{x,o} = C_2 - \left(\frac{C_1 C_3}{C_2}\right)\left(\frac{d_1 - d_2}{d_2 + d_3}\right) \quad (15)$$

where $\mathbf{C_1}$ is the minimum concentration measured at distance d_1 in the downwind direction from the source, C_2 is the maximum concentration measured at distance d_2 in the downwind direction from the source, $\mathbf{C_3}$is the concentration measured at distance $\mathbf{d_3}$ in the upwind direction from the source. By applying the boundary and initial conditions, we can calculate the values of p's and q's and the exponents by conducting the experiments at different sites with different conditions but on the same kind of sources. The software "DataFit" was used for analyzing the data and solving the system of (**m**+**n**+1) homogeneous linear equations. The emission of sulfur dioxides (SO_2) is comparatively less than the suspended particulate maters (SPM) and further it is negligible in coal washery complexes.

However, the empirical equations have been derived for estimating the emission rates of both suspended particulate maters (E_p) and sulfur dioxide (E_g) from major of sources and activities. In the following empirical equations, **m** stands for moisture content of the material (%), **s** for the silt content of the material (%)**u** for wind speed (m/s), **f** forfrequency (No. of trips / hr), **h** for dropping/loading/source height, **c** for capacity of the unit (tones), **v** for average vehicle speed (km/hr), **w** for average number of wheels, **a** forexposed area of the source (m^2). Further, **n** stands for the number of rotations per hour (No./hr), **y** foryield or production rate (tones/hr), **d** for diameter of the rotary sphere (m), **A** for unclosed area of the rotary crusher system (m^2), **q** for average flow rate of the material transported through conveyer belt (tones/hr), **v** for velocity of the conveyer-belt (m/s).

Air quality prediction

The air quality dispersion model for the prediction of air quality in and around the coal washery has been carried out with the aid of a supper computer. The study window was divided into finite number of grids. The center of each grid is assumed to be the location of different sources that falls in the respective grids. However, the kind of each source, source height from the ground, their respective emission rates will be duly considered for the prediction of air quality whereas the wind speed and climate condition is assumed as the same. But when the altitude of the topography varies in the downwind direction, the temperature also varies. In such a situation, the program predicts the temperature using the model and the influence of the temperature on air quality has been duly incorporated in the model.

Surface plan of the industry showing the locations of various operational units like coal stack yard, screening section, primary crusher, secondary crusher, chuts or drop-points of conveyor belts, exposed piles, thermal dryers, exposed surface containing coal dusts etc was prepared. The study area was divided into grid size of 100mX100m in order to mark the area occupied by the various operational units and other sources of air pollutants. The weighted average of wind speeds (km/hr) taking the percentage of hours prevailed with the ranges classified as 1.6-5, 5-10, 10-15 and 15-20 km/hr as the weightages in the different prevailing directions were calculated using the wind-rose diagrams of summer and winter seasons. The emission rates of SPM and SO_2 from the identified major sources were estimated using the empirical emission models. The concentration of air pollutants will be diluted in the atmosphere and it will be reduced significantly due to the inversion effect when the temperature is very high. The concentration of air quality may be high during morning, evening and night hours than noon hours in and around the coal washery complexes.

Therefore the prediction of air quality in the prevailing directions with the respective average wind speed was predicted with the interval of 25m in both longitudinal (X-axis) and latitudinal (x-axis) distances for summer and winter seasons to evaluate the present model. In order to assess the optimized impact the maximum values of the SPM and SO_2 concentrations at the each grid were assessed using spreadsheet (Microsoft excel) and the isopleths of the concentration of the air quality parameters were plotted using the software "SURFER". The isoploth of the SPM and SO_2 for both summer and winter season have been presented in **Figs.5 to 7.**

3. Results and discussion

Empirical emission formulae on various sources of air pollutants in order to estimate the emission rates of various significant sources have been developed based on the experimental data generated from various field studies. These emission formulae have been evaluated through statistical analysis. The estimated empirical coefficients are based on the experiments conducted in the field. If more experiments would be conducted and the results would be used for estimating the unknown empirical coefficients, exponents and constants, the percentage of error may be minimized and the accuracy of the prediction may be brought through the empirical models. However, it has been observed that $\pm$6.1% of error occurs in the predicted emission rates of suspended solid matters (SPM) with reference to the field data and $\pm$5.23% in the emission of sulfur dioxide (SO_2) from all identified major sources. The predicted SPM and SO_2 concentrations in summer at Mahuda coal washery complex are 423 $\mu g/m^3$ and 37.5$\mu g/m^3$ respectively, which falls in the interval, constituted with minimum and maximum values of field experimental data, viz., 402 - 457.3$\mu g/m^3$; 30 - 40.32$\mu g/m^3$ respectively. Further, the predicted SPM and SO_2 concentrations in winter at site are 555 $\mu g/m^3$ and 21$\mu g/m^3$ respectively which falls in the ranges 535 - 579$\mu g/m^3$; 23 - 98.8$\mu g/m^3$ respectively.

The predicted SPM and SO_2 concentrations in summer at Munidih coal washery complex are 392 $\mu g/m^3$ and 69.3$\mu g/m^3$ respectively which falls in the interval constituted with minimum and maximum values of field experimental data, viz., 375 - 426$\mu g/m^3$; 45 - 75.4$\mu g/m^3$ respectively, whereas in winter, predicted SPM and SO_2 concentrations are 496.7$\mu g/m^3$ and 47.3$\mu g/m^3$ respectively, which are falling in the intervals 472.5 - 507.18$\mu g/m^3$; 43 - 62.13$\mu g/m^3$ respectively. Similarly, for other coal washery complexes, the predicted and field experimental data were compared and it was found that the predicted air qualities through modeling and simulation are very close to the data obtained in the laboratory by analyzing the ambient air samples. It has been found that 5 - 10% error occurs in the predicted air quality. Therefore, the present model can be used as a tool to visualize the impact of coal washeries on the surrounding.

As it has been observed that SPM is the major source of pollution in and around the coal washery complexes and it has been perceived through the study that the haul roads are the significant sources among all other identified sources. It is necessary to sprinkle water along the haul roads of the washery complexes to suppress the particulate matters of the aerodynamic diameter less than 10μ. It has been found that the crusher points, drop-points of conveyer belts, screening sections are the significant sources in continuously transporting the particulate matters into the atmosphere. Therefore, it is recommended that installation of water sprinkling system in the prevailing wind direction in order to control air pollutants. It has been endorsed that raw piles of raw coals should be packed properly and made more compact using bigger size material on the top to arrest the fine particles so that the wind may not enter inside and take away them into the atmosphere. Similarly, the piles of clean coal, middling and rejects must be stored in such a place where the wind cannot have any influence on them to drive up the fine particulate matters into the atmosphere.

The areas in the surrounding of screening section, the stockyards, crusher point and the both sides of the haul roads may be curtained with suitable vegetation in order to arrest the dust transported into the atmosphere. Certain evergreen plants, grasses and epiphytes like orchids could control the concentration of SPM. A study has reported that certain plants have remarkable dust filtering, air cleaning, and air purifying capacities. The plants with simple leaves such as Peepal (*Ficusbenghaiensis*), Mast (*Polualthia*), Mango (*Mangiferaindica*), Teak (*Tectonagrandis*), Sal (*Shorearobusta*), Arjuna (*Terminalisarjuna*), etc. are better dust collectors than the plants with compound leaves like gulmohar (*Ponciamaregia*), tamarind (*TamarindusindicaL*.), Amaltas (*Cassiafistula*) and neem (*Azardirchtaindica*) [9, 10] The plantation of local plant species along the peripheral of the washery lease area may be very much fruitful in controlling the emission of particulate matters from operations of various units of a coal washery complex.

Acknowledgements. This is the outcome of the research work carried out for the award of Ph.D by Ms.R.JudithKiruba, who is the Part-time Category-'C' National Research Scholar of M.S. University, Tirunelveli, Tamil Nadu. The authors are grateful to the Director, CSIR-Central Institute of Mining and Fuel Research, Dhanbad for his constant encouragements during their research work and providing necessary infrastructural support during the study. The authors are also thankful to Dr.M.K.Chakraborty, Principal Scientist for extending his kind help and valuable support during the period of sampling and analysis of air samples

REFERENCES

1. M.Sundararajan, V.J.Loveson, A.Chattopadhyay and R.Venugopal, Impact of coal preparation plants on nearby fluvial systems and assessment through mathematical modeling and computer simulation, *International Conference on challanges in Coal & Mineral Benefeciation*, Organized at I.S.M, Dhanbad, (2002) 303-310.
2. B.Madhave Rao, Air pollution in coal minning and coal based inndustries and their general effect, Imapct of minning on the environment, *Proceeding of International Symposium*, (1994) 35-44.
3. M.Sundararajan, Computer application of air pollution modeling and meteorological studies, Lecture Material for a Course on Computer Application on Industrial Pollution Cotrol (Training .under Industrial Component of World Bank Aided Industrial Pollution Control Project), February 12-16 (1996) 75-85.
4. M.Sundararajan, Ph.D Thesis entitled Mathematical Modeling of Fluid Components Transport for the Prediction of Environmental Parameters in and around Coal Washery Complexes, Dept. of Appl. Maths., Indian School of Mines, (2004).
5. Environmental Protection Agency (1992) User's guide for the Industrial Source Complex(ISC2) dispersion models, Volume-I, User's instruction office of air quality planning and standard, North Caroliva.
6. F.A.Gifford, Use of routine meteorological observations for estimating atmospheric dispersion, *Nuclear Safety*, 2 (1961) 47-57.
7. G.K.Banerjee, K.K.Srivastava, M.K.Chakravarty and M.Sundararajan, An approach towards the estimation of emission rates from various activities of naomundih iron ore mine – case study, *Journal of Scientific and Industrial Research*, 62 (2002) 339-343.
8. M.Sundararajan, G.K.Banerjee, K.Nikhil and D.D.Misra, Air quality dispersion scenario at noamundi iron ore mine through mathematical modelling and computer simulation - a case study, National Symposium on Sustainable Mining Technology: Present and Future, Organzed by Anna University at Chennai 14-15th March 2002.
9. R.Wilson and J.Spenglerm, Conclusion: policy implication: the national dilemma, In: particles in our air: concentration and health effects, Wilson R, Spengler J D (eds), Cambridge, MA, USA, Harvard University Press,205-216.

10. L.G.R.Chhrq, Environmental air pollution and its control, New Delhi, (1989).

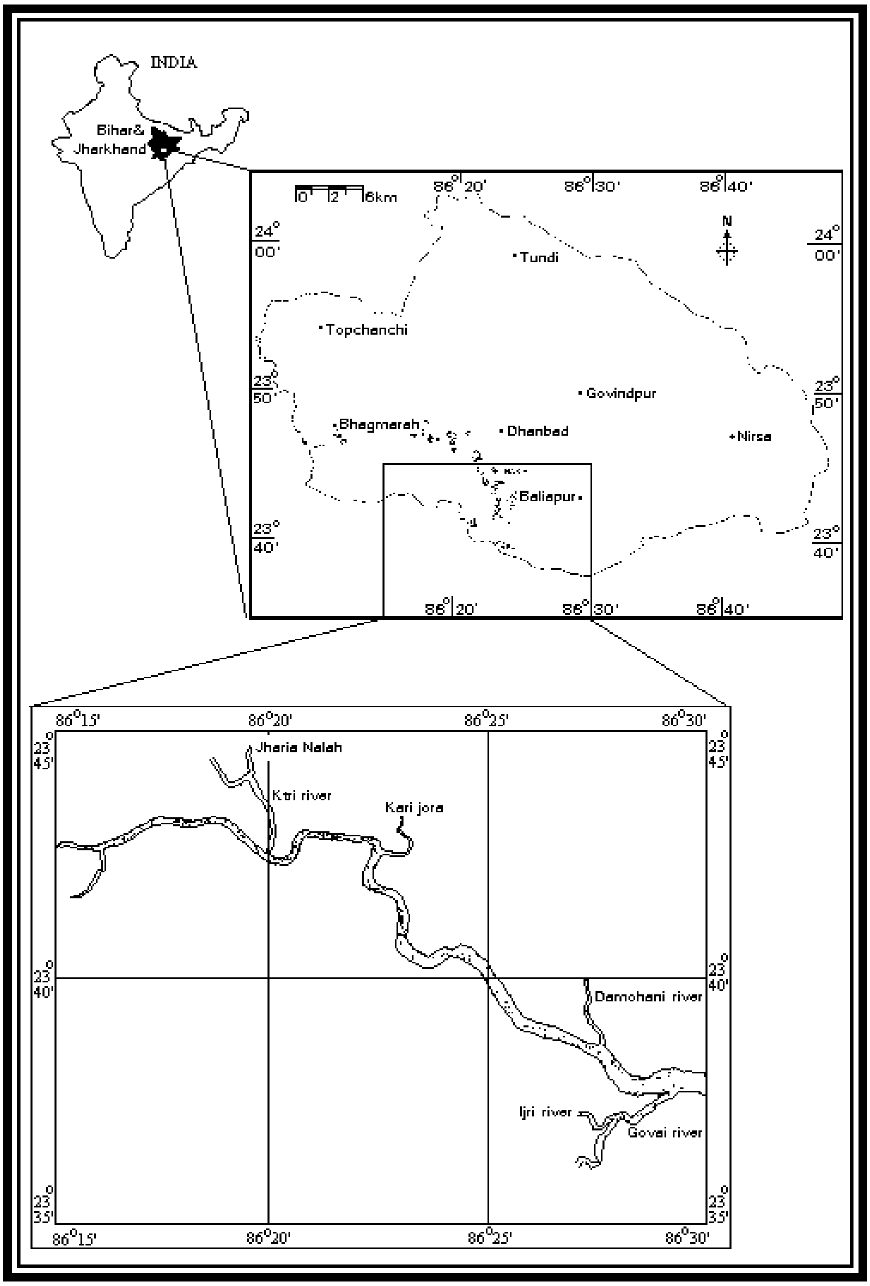


Figure 1: Location map of the study area

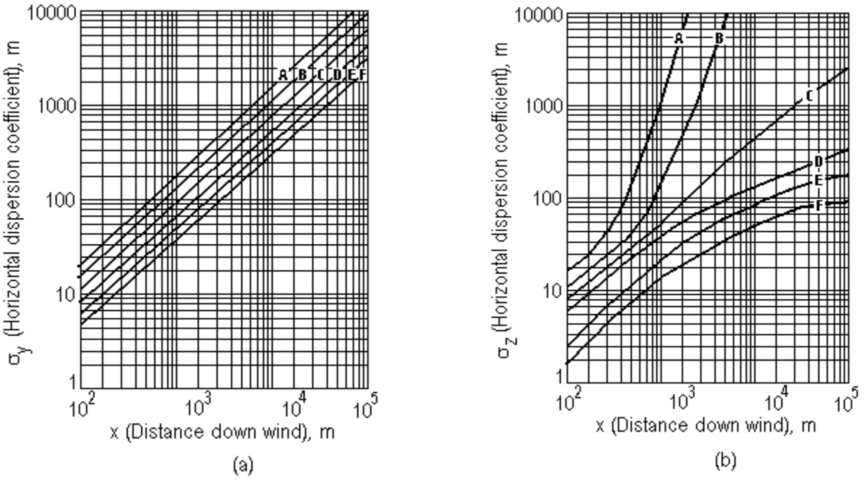


Figure 2: Gaussian Plume Modeling: Pasquill–Gifford coefficients, where (a) Horizontal dispersion coefficient: (b) Vertical dispersion coefficient

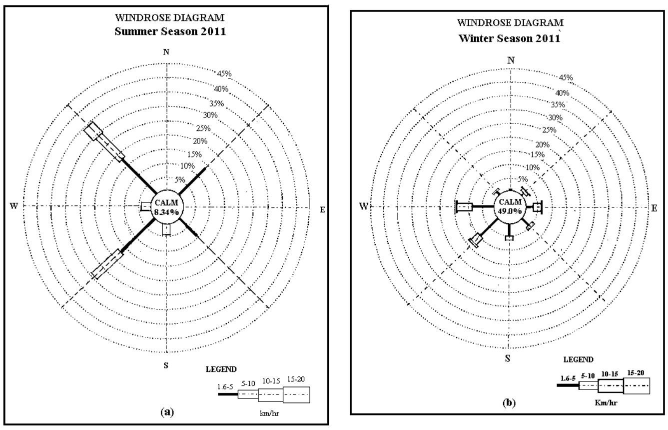


Figure 3: Wind-rose diagram showing the different classification of the wind speeds and prevailing wind directions during (a) summer and (b) winter

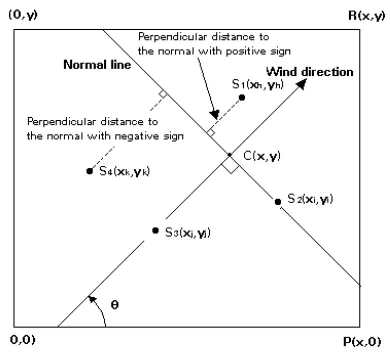
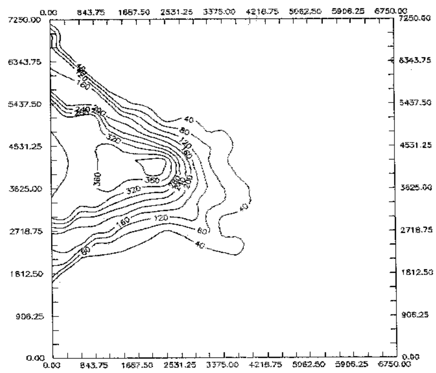
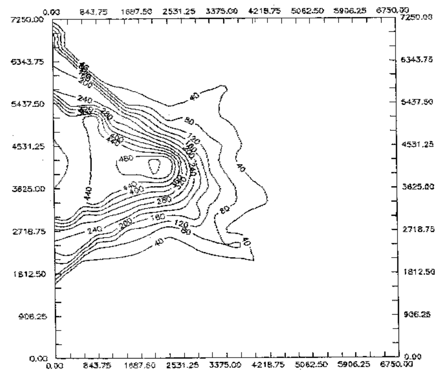


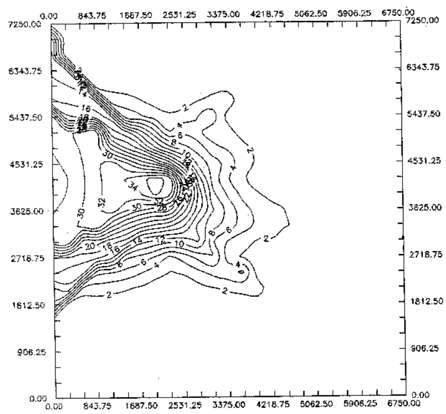
Figure 4: A hypothetical study window for the prediction of air quality. Here O, P, Q, Q are the corner points, S_1, S_2, S_3, S_4 are sources and P is the air quality prediction point



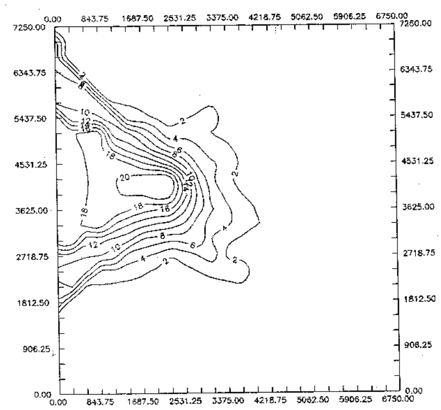
Dispersion of suspended particulate matters (μg/m^3) during summer



Dispersion of suspended particulate matters (μg/m^3) during winter



Dispersion of sulfur dioxide (μg/m^3) during summer



Dispersion of sulfur dioxide (μg/m^3) during winter

Figure 5: Dispersion of air quality in the Mahuda coal washery complex of the first sub-window of the study area in summer and winter seasons

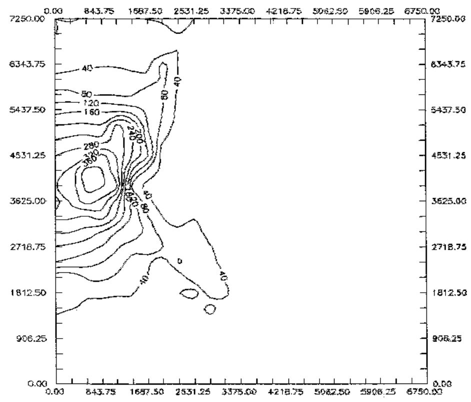
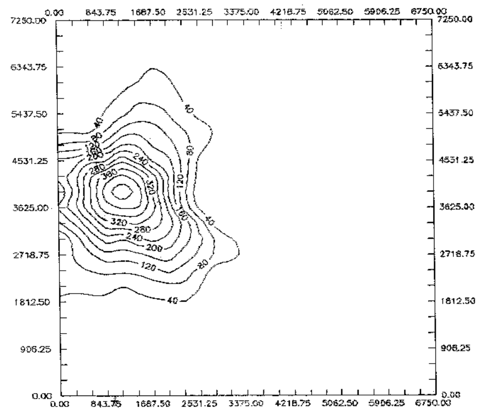
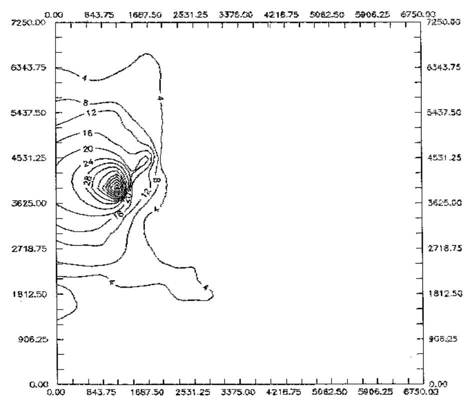
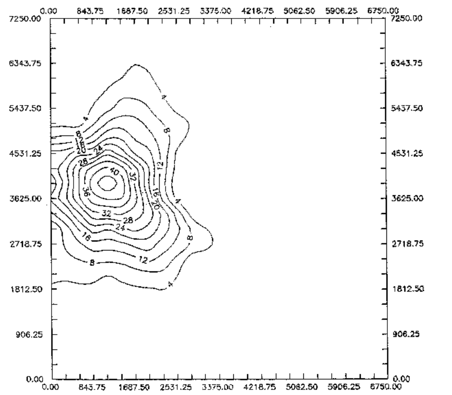
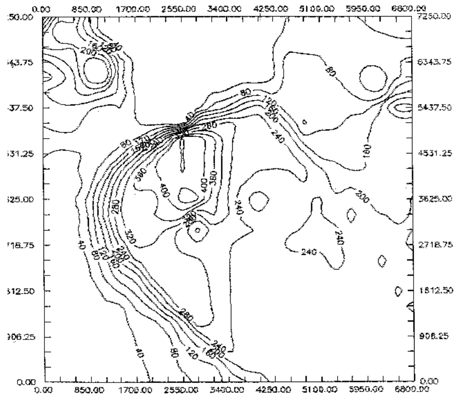
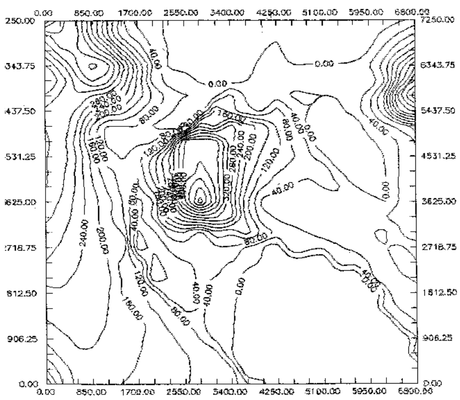
	
Dispersion of suspended particulate matters ($\mu g/m^3$) during summer	Dispersion of suspended particulate matters ($\mu g/m^3$) during winter
	
Dispersion of sulfur dioxide ($\mu g/m^3$) during summer	Dispersion of sulfur dioxide ($\mu g/m^3$) during winter

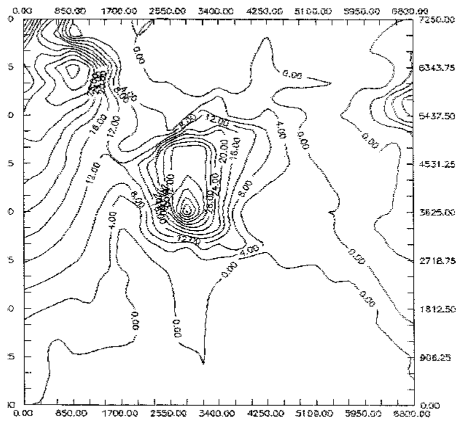
Figure 6: Dispersion of air quality in the Munidih and Jamadoba Coal Washery complexes of the second sub-window of the study area in summer and winter seasons



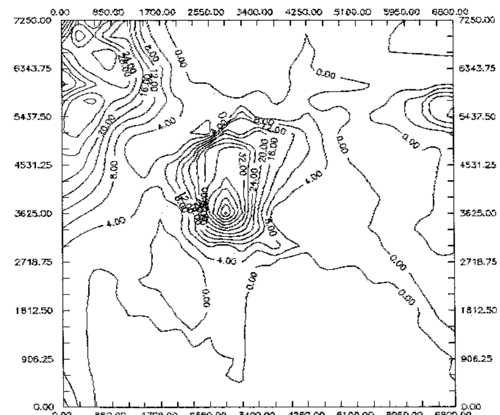
Dispersion of suspended particulate matters ($\mu g/m^3$) during summer



Dispersion of suspended particulate matters ($\mu g/m^3$) during winter



Dispersion of sulfur dioxide ($\mu g/m^3$) during summer



Dispersion of sulfur dioxide ($\mu g/m^3$) during winter

Figure 7: Dispersion of air quality in the Munidih and Jamadoba Coal Washery complexes of the third sub-window of the study area in summer and winter seasons