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An urban diffusion model for Delhi using computer techniques*

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सार — दिल्ली में सल्फर डायआक्साइड की सांद्रता के आकाशीय तथा कालिक परिवर्तन प्राप्त करने के लिये क्षेत्र उत्थित बिन्दु तथा गतिमान स्रोतों सहित स्रोत के रूप में एक शहरी विसरण निदर्श (मॉडल) उपयोग किया जा रहा है। यह निदर्श हन्ना द्वारा विकसित निदर्श पर आधारित है। निदर्श द्वारा संगणित औसत तथा अधिकतम सांद्रताएं अनुश्रवित मानों से बहुत अधिक मिलती हैं।

ABSTRACT. A source oriented urban diffusion model for Delhi with area, elevated point and moving sources, based on the model developed by Hanna is utilised in obtaining spatial and temporal variations of SO_2 concentrations. Average and maximum concentrations computed by the model fairly agreed with the monitored values.

1. Introduction

An urban area is a source of numerous pollutants and of these sulphur dioxide is common. Concentration of pollutants at any place and time can be known either by direct monitoring or by modelling. While monitoring is expensive and time consuming, modelling is economical. There are several urban diffusion models to determine space and time variations of pollutants and of these, source oriented model, receptor oriented model, statistical model, tabulation prediction scheme and numerical technique deserve mention. Each technique has its own advantages and limitations. Out of all these, the source oriented model is less time consuming and easy to handle for land usage and planning purposes.

In the present study the simple and realistic source oriented model of Hanna (1971) was suitably modified to accommodate the available data of Delhi. The simple models similar to Hanna (1971) are often successful because area source dispersion is an integral problem, in which the area under distribution curve is important, rather than the variation along the distribution curve itself. In an urban area effluents are released from area, point (elevated or ground) and moving sources. In this model area source emissions are regarded as the sum or integral of numerous small point source including vehicular traffic etc across a broad area. Concentration contribution due to large elevated point sources are calculated separately. The pollutants are considered to be non-reactive. Considering the region as a flat terrain, only single wind vector for each hour has been assumed valid for the whole urban area. Mixing depths have not been considered. In the present paper are presented the space and time variation of sulphur dioxide in Delhi as obtained by the above urban diffusion model.

2. Methodology

An urban air pollution model necessitates the knowledge of source inventory, meteorological data, the mathematical algorithm which describes the process that transforms the concentration at the source to those observed at the receptor and validation techniques.

(a) *Source inventory*

Emission of sulphur dioxide in Delhi from 360 industries in six industrial belts is estimated to be 175 tonnes of SO_2 per day. Likewise emissions of SO_2 from automobiles are estimated to be 2 tonnes per day (Personal communication from Central Board for the Prevention and Control of Water Pollution). The elevated sources in Delhi are Inderprastha and Raj Ghat Power Houses; details of emissions of which have been obtained directly from the respective power plant authorities. For convenience to locate the sources of pollution, Delhi has been devided into 9 × 6 square grids of 4 km each; nine grids from north to south and six grids from east to west. The total estimated discharge of SO_2 is 175 tonnes per day is assumed to be released uniformly

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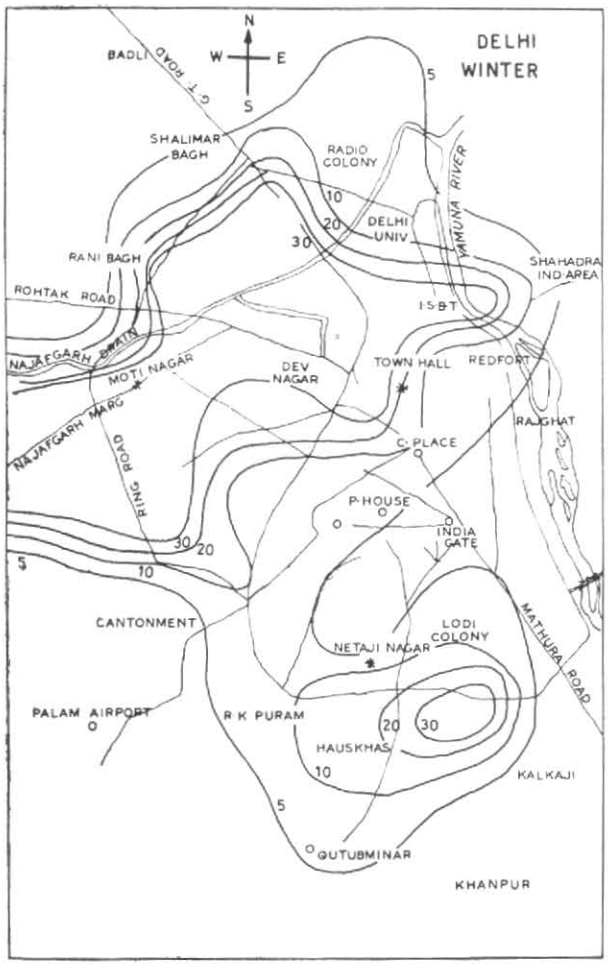

Fig. 1. Model estimates of surface SO_2 concentrations ($\mu g/m^3$) for Delhi (Winter)

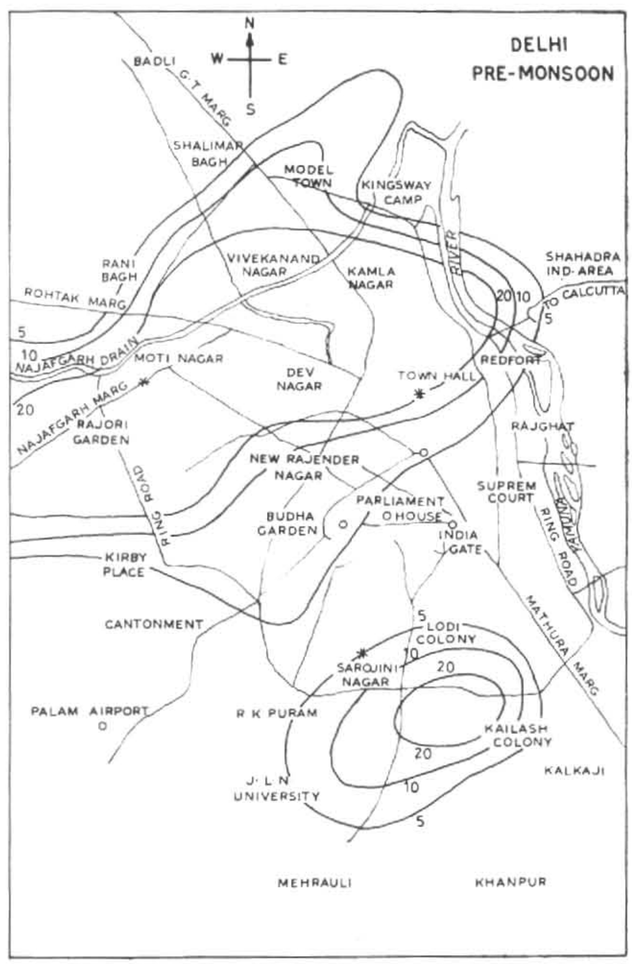

Fig. 2. Model estimates of surface SO_2 concentrations ($\mu g/m^3$) for Delhi (Pre-monsoon)

from six industrial belts falling in 12 grids. The area emission thus comes out to be 1.0 μ g/m^2 sec. Similarly, vehicular discharge of 2 tonnes/day is assumed to have been uniformly released from the 21 traffic artery grids which came out to be 0.07 μ g/m^2 sec.

(b) *Meteorological data*

As the terrain features of Delhi are more or less flat, wind from a single observatory is considered to be reasonably approximate the flow over the entire area. Similarly single stability class for each hour is assumed to be representative of the whole area. Therefore, hourly wind speed, direction and stability recorded at Safdarjung observatory for the period 1966-75 have been utilized. Frequency tables for wind speed-direction and average stability for each hour of the twelve months have been prepared.

(c) *Mathematical algorithms*

The surface concentration χ of a pollutant due to emissions from an area source is a function of the distribution of area source strength, the wind speed and direction and the atmospheric stability. The area source distribution is assumed to be relatively smooth. This assumption permits us to neglect the horizontal cross wind component to the diffusion in comparison with the vertical component.

Source of emission have been distributed into a square grid distances of 4 km. According to Gifford (1959), the surface concentration χ (μg/m^3) due to across sources upwind of the receptor point can be computed :

$$\chi = \int_0^{\triangle} \sqrt{\frac{2}{\pi}} \frac{Q_A}{u\sigma_z} \, dx \tag{1}$$

where Q_A (μg/m^2 sec) is source strength, D(m) is the distance to the edge of the urban area, u(m/s) is the wind speed and σ_z (m) is the standard deviation of the vertical distribution parameters.

The vertical distribution of the pollutants is assumed to be Gaussian or normal, with standard deviation σ_z. Smith (1968) suggests the following relationship for σ_z.

$$\sigma_z = ax^b \text{ (}x\text{ is the distance in metres)} \tag{2}$$

where a and b are the constants which depend upon the stability of the atmosphere. Furthermore, stable conditions do not often occur over urban areas because of the heat input from the urban surface during the night. It is assumed that in an urban area either unstable or neutral conditions occur.

If the receptor is at the centre of grid block 'o', with grid distances $\triangle x$, and the wind blows in only one direction, the Eqn. (1) can be written as the summation over grid squares upwind of the receptor square:

$$\chi = \sqrt{\frac{2}{\pi}} \frac{(\triangle x/2)^{1-b}}{ua(1-b)} \left[Q_{A0} + \sum_{i=\pm 1}^{i=\pm 4} Q_{Ai} \left\{ (2i+1)^{1-b} - (2i-1)^{1-b} \right\} \right] \tag{3}$$

The source strengths Q_{A1}, Q_{A2}, Q_{A3} applying to the grid square in which the receptor is located, the grid square upwind of the receptor square, and so on, respectively. The integration is arbitrarily terminated after four grid squares. The relative weight of source strengths for grid blocks 0, 1, 2 ... is 1, 0.31, 0.19, 0.13, 0.10, ... when b equals 0.75 for neutral stability. For N equals, to four, summation of the constants outside of central grid block is, thus, more heavily weighted than the strengths of other blocks combined. If the frequency with which the wind blows from the 16 major directions is known, then Eqn. (3) becomes the double summation:

$$\chi = \sqrt{\frac{2}{\pi}} \frac{(\triangle x/2)^{1-b}}{ua(1-b)} \left[Q_A(0,0) + \sum_{i=\pm 1}^{i=\pm 4} \sum_{j=\pm 1}^{j=\pm 4} Q_A(i,j) f(i,j) \left\{ (2r+1)^{1-b} - (2r-1)^{1-b} \right\} \right] \tag{4}$$

when the 16 point wind direction frequency distribution is put into the program, the parameter $f(i, j)/u$ and $[(2r+1)^{1-b} - (2r-1)^{1-b}]$ are calculated within the program through 9 by 9 matrix where u is the average wind speed in that sector.

The concentrations χ in the central square and other 4 squares can be obtained by multiplying each element of $f(i, j)/u$ and $[(2r+1)^{1-b} - (2r-1)^{1-b}]$ with the corresponding element of Q_A (i, j) of the source matrix.

The wind frequency $f(i, j)$ and u for Delhi have been obtained for period of ten years data from 1966-1975.

Similarly, the surface concentration χ (μg/m^3) of pollutant in any grid due to point source strength Q_p (μg/sec) is obtained using Gaussian plume formula (Slade 1968) utilizing 16 point wind direction frequency distribution:

$$\chi = \sqrt{\frac{2}{\pi}} \frac{fQ_p}{\sigma_z \, ur \, 2\pi/16} e^{-H^2/2\sigma_z^2} \tag{5}$$

where H is the effective source height, r is the distance of the receptor point from the source, and f is the frequency with which the wind blows towards the sector of interest. The effective source height H is the sum of the physical stack height h_s and the plume rise h_p calculated according to Padmanabhamurty and Gupta (1980).

Eqn. (5) can be used in order to estimate the average concentration in the grid square in which the point

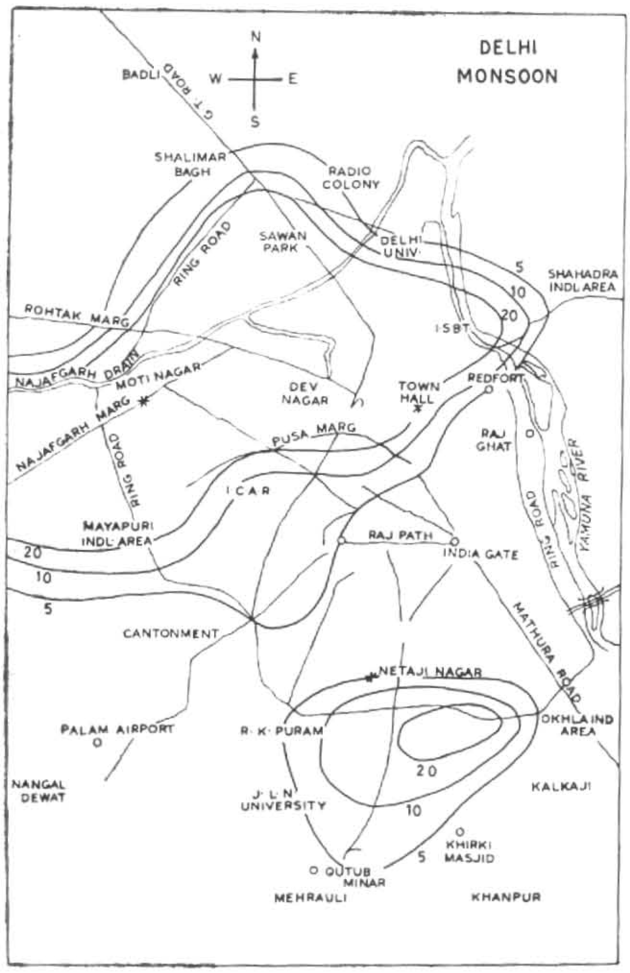

Fig. 3. Model estimates of surface SO_2 concentrations ($\mu g/m^3$) for Delhi (Monsoon)

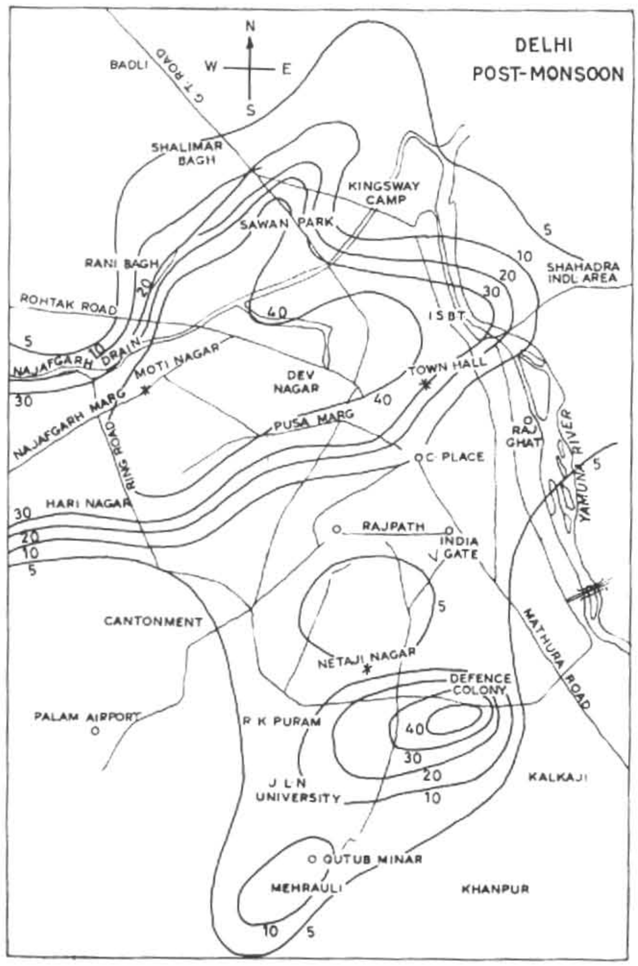

Fig. 4. Model estimates of surface SO_2 concentrations ($\mu g/m^3$) for Delhi (Post monsoon)

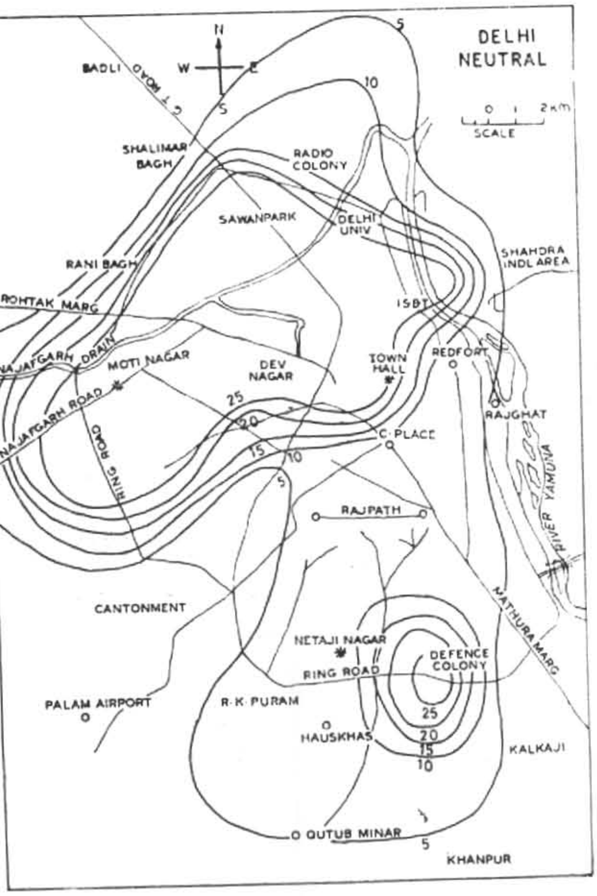

Fig. 5. Model estimates of surface SO_2 concentrations ($\mu g/m^3$) for Delhi (Neutral)

source is located. The source is assumed to be located in the centre of the square and the average concentration in the circle with radius $\triangle x/2$ is assumed to be equal to the average in the square with side $\triangle x$. Also since there is only one wind direction sector for the source square, the fraction $2\pi/16$ in Eqn. (5) becomes 2π and frequency f equals one.

$$\chi_{s.s.} = \frac{1}{\pi(\triangle x/2)^2} \int_0^{2\pi} d\theta \int_0^{\triangle x/2} \sqrt{\frac{2}{\pi}} \frac{Q_p}{ax^b u . 2\pi} e^{-\frac{H^2}{2a^2 x^{2b}}} dx \tag{6}$$

where suffix s.s. is souice square.

The equation is being integrated numerically by the computer given the input parameters $\triangle x$, Q_p, a, b, H and u. It is found that the average concentration due to a ground level ($H=0$) point source located in the middle of the grid square to equal to the average concentration due to a uniform area source in that grid square, *provided that* Q_p *equals* Q_A $(\triangle x)^2$, *i.e.*, the total emissions in the square are equal. The average concentration χ in grid squares other than the source grid square is assumed to equal the concentration in the centre of the square calculated using Eqn. (5). Gifford's reciprocal plume concept is then used to estimate the total surface concentration in a grid square due to contribution from the given distribution of point

TABLE 1

Long term concentration ($\mu g/m^3$)

Season	Measured by NEERI during 1978-79 at			Computed by the present model at		
	Netaji Nagar	Town Hall	Najafgarh	Netaji Nagar	Town Hall	Najafgarh
Winter	7	48	36	7	20	>30
Pre-monsoon	5	37	70	5	20	>20
Monsoon	3	22	36	5	20	>20
Post-monsoon	19	64	33	7	30	>40

sources by super-imposing a 9×9 matrix over the source grid and multiplying term by term. This is done in the program by classes of effective stack height.

3. Results and discussions

The total (average) concentration of SO_2 ($\mu g/m^3$) due to area and elevated sources and vehicular traffic were plotted on a map of Delhi and isopleths were drawn for all the four seasons and presented in Figs. 1 to 4. It can be seen that two pockets of 40 $\mu g/m^3$ average maximum concentration of SO_2 appear in post-monsoon season encompassing some of W, WNW and N parts of Delhi and the other at Defence Colony-Lajpat Nagar area. These pockets of maximum values reduced to 30 $\mu g/m^3$ during winter and to 20 $\mu g/m^3$ in the remaining seasons of the year.

The isopleths under neutral condition (Fig. 5) based on 10 years data have also been prepared. In an urban area as already stated it is assumed that nearly neutral or average conditions generally prevail. The vertical extent of the effect of urban heat input may not be high some times. In such cases the stable conditions over the urban neutral layer restricts vertical dispersion resulting in build-up of concentrations.

Under neutral conditions (Fig. 5) average conditions over urban areas (Delhi) — maximum concentration of 25 $\mu g/m^3$ occurs in two pockets. The model computations are in good agreement with the monitored values reported by NEERI and given in Table 1 for comparison.

4. Conclusions

The coincidence of results computed and monitored though fortuitous, suggests that the methodology is capable of yielding good results. Attempts are being made to obtain better emission inventory, spatial and temporal variation of meteorological and pollution data to improve the model for general application.

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