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DISPERSION OF SULPHUR DIOXIDE AROUND THE THERMAL POWER PLANT AT AHMEDABAD, INDIA

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Abstract—Air quality due to the release of sulphur dioxide from the thermal power plant within the city limits of Ahmedabad has been computed employing a point, area and line dispersion model. To estimate probable air quality, the meteorological data for 3 consecutive days in the middle of each month of 1983 is used. The concentration of sulphur dioxide is computed at a distance of every 500 m in 16 directions up to the city limit. The air quality in the worst case is estimated in downwind distances under unfavourable meteorological conditions.

The probable zones of high concentrations of sulphur dioxide over residential, commercial and industrial areas of the city are below the ambient air quality standards set by the U.S. EPA in 1971 almost throughout the year. However, in the months of April and October the zone of high concentration (500 $\mu g\,m^{-3}$) exceeds the EPA standard. Also, under the most unfavourable meteorological conditions, the estimated high ground-level concentration of sulphur dioxide can reach up to 1000 $\mu g\,m^{-3}$ at a distance of 1.25 km from the thermal power plant. This may be attributed to the effect of fumigation.

Key word index: Dry deposition, sulphur dioxide, power plant, dispersion model.

1. INTRODUCTION

The thermal power plant is located in Ahmedabad (23°4′N, 82°38′E, 55 m above msl) which is one of the most industrialized and heavily populated cities in India. Thermal power generation is the largest source of SO_2 in the city besides other industrial processes. It is commonly understood that sulphur dioxide reduces atmospheric visibility, damages various materials and agricultural crops and is detrimental to human health. When sulphur dioxide is oxidized and hydrolysed it gives rise to acid rain. The impact of acid rain on the aquatic ecosystem, plant–soil system and acidification of lakes is well documented. The quantitative estimation of the long-term averages of SO_2 and fly ash have been dealt with by many (Patil and Patil, 1990; Goyal and Singh, 1990; Raghavan *et al.*, 1983; Padmanabhamurty and Gupta, 1977). However short-term averages of SO_2 are more important as they cause acute environmental effects. According to the federal standard, the short-term exposure (24-h average) of 800 $\mu g\,m^{-3}$ of SO_2 is the alert level. Concentrations of SO_2 exceeding this limit can have serious effects on human health and sensitive plants. Bearing in mind these facts, the present study was undertaken to evaluate air quality due to the release of SO_2 from the thermal power plant at Ahmedabad. The air quality impact of this source is evaluated by the use of a dispersion model. The urban diffusion models which permit quantitative determination of ambient air concentrations in relation to emission sources and meteorological conditions are widely used in regulation and urban planning for impact analysis of existing or new sources and evaluating control strategies.

In the present study air quality due to the dispersal of sulphur dioxide from the thermal power emission in the city of Ahmedabad has been calculated using a point, area and line dispersion (PAL) model based on Gaussian distribution. The results of this computation are presented in this paper.

2. MODEL

There are several urban diffusion models to determine space and time variation of pollutants. A recommended Gaussian model is used to calculate the concentration of SO_2 due to emission from continuous elevated sources (Petersen, 1978). The basic equation involved for evaluation of ground-level concentration C of sulphur dioxide at a receptor is given by

$$C=\frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left\{\exp\left[-\frac{(Z-H)^2}{2\sigma_z^2}\right]+\exp\left[-\frac{(Z+H)^2}{2\sigma_z^2}\right]\right\},$$

where Q represents the source strength and H is the effective source release height; dispersion parameters σ_y and σ_z are the standard deviations of the plume concentration in the horizontal and vertical directions, respectively; Z is the receptor height, u is the wind speed and y is crosswind distance. The diffusion coefficients σ_y and σ_z were calculated as prescribed by Turner (1970). Effective plume rise at different distances from the sources are calculated (Briggs, 1969).

The downwind and crosswind distances of the receptors from the thermal power plant are calculated as

$$x = S\cos T + R\sin T$$

$$y = S\sin T - R\cos T,$$

respectively, where R and S are east and north coordinates of the receptor and T is the wind direction. The pollutant is assumed to be non-reactive and its removal and transformation rates are not considered. The site terrain is assumed to be flat and the height of the receptor is 1 m above the ground.

3. INPUT PARAMETERS

Ahmedabad is a densely populated city with a large industrial belt located on the northeast–southeast sector of the city. The residential colonies of the city are mainly located in the northwest and southwest directions. The central part of the city in the southern direction is a commercial area with busy locoyards, shopping centres, banks, offices, bus termini, etc. Figure 1 shows the location of the thermal power plant (TPP) and the municipal boundary of Ahmedabad city as a dashed line. The figure also shows the residential, commercial and industrial areas of the city.

3.1. *Pollution sources*

The thermal power plant at Ahmedabad is situated in the northern direction of the city near the Sabarmati river. The capacity of the power plant is 381 MW and its daily coal consumption is about 4300 tonnes (Shishoo and Prakash, 1985). It is estimated that about 1800 kg of SO_2 are emitted per hour from the stacks of the plant. The estimated emission of SO_2 is based on the typical sulphur content of 0.5% of Indian coal. It has 10 stacks of differing heights emitting SO_2. The data for the 10 stacks of the plant are given in Table 1 (Ananthakrishnan and Soman, 1989).

Since the emission rate of SO_2 from each stack was not available, it is assumed that an equal amount of SO_2 is emitted from each stack. However, actual emission rates may vary from one stack to another.

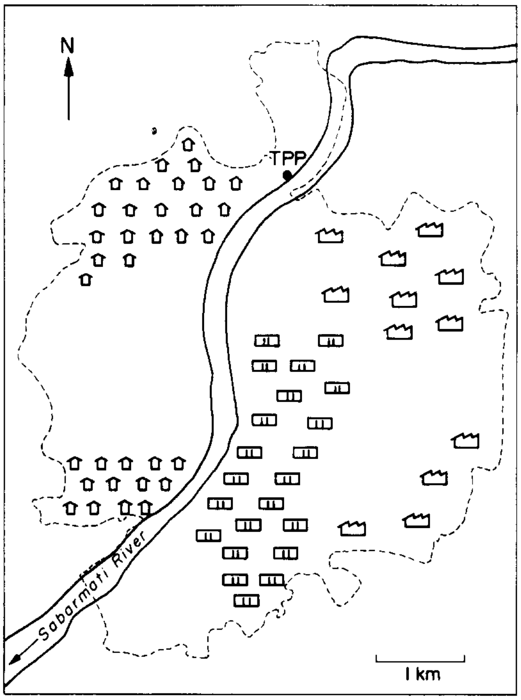

Fig. 1. Map of Ahmedabad showing the location of the thermal power plant, residential, commercial and industrial areas and municipal boundaries (- - -) of the city.

3.2. *Meteorological data*

The meteorological data for fixed hours, namely 0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 GMT for selected days in 1983 are obtained from the India Meteorological Department and used for the computation of SO_2 values for averaging for a day. For the estimation of mixing height, radiosonde data from Ahmedabad for 0000 GMT are used from the routine observations taken by the India Meteorological Department. The average meteorological condition over the city during the period under consideration is given in Table 2. Wind roses during the period of interest are shown plotted in Fig. 2.

3.3. *Determination of mixing height*

There are several methods currently available for the estimation of mixing heights, the more important being those using temperature profiles measured on a fixed tower or by sonde and by remote sensing techniques. In the present study, the mixing height (MH) is calculated by using a method based on temperature profile measured by radiosonde ascent at Ahmedabad (ISI, 1978). According to this convention, the MH is calculated as the height above the ground at which the dry adiabatic lapse rate (DALR) extension of the maximum surface temperature of the day intersects the environmental lapse rate (ELR) at 0000 GMT. Since MH is required at every 3 h, a slight modification is made. Radiosonde data for selected days are plotted on a T–ϕ-gram. Mixing height at every 3 h is then graphically calculated as the height above ground at which the DALR extension of the prevailing temperature at that hour intersects the ELR at 0000 GMT. Radiosonde data for Ahmedabad city for 1983 is obtained from the India Meteorological Department.

3.4. *Determination of atmospheric stability*

Practical methods of classifying atmospheric stability for use in Gaussian-type dispersion models have traditionally relied on the surface heating approach. But the only available data in most routine applications are parameters such as wind speed, cloud cover and, in a few cases, insolation. In the present study Pasquill's classification is used to determine atmospheric stability (Pasquill, 1962).

Table 1. Data relating to stacks of the thermal power plant at Ahmedabad

No of stacks	Height (m)	Stack radius at exit (m)	Plume temp. at exit (°C)	Flow rate ($m^3 s^{-1}$)	Vertical speed ($m s^{-1}$)
4	30.70	1.46	169	37.75	5.64
2	46.05	1.69	173	45.58	5.08
2	46.05	1.69	163	24.55	2.74
2	91.50	1.95	148	126.00	10.55

Table 2. Average values of some of the surface meteorological parameters at Ahmedabad for 3-day periods in different months in 1983

Month	Temp. (°C)	Cloud cover (oktas)	Wind speed ($m s^{-1}$)
January	16.9	0	3.4
February	20.0	0	2.7
March	27.9	0	2.8
April	29.2	1.4	3.3
May	38.1	1.6	2.5
June	35.4	4.4	3.0
July	27.2	6.8	2.2
August	27.1	6.7	2.6
September	29.3	4.5	1.7
October	26.3	1.7	1.2
November	21.7	0	2.2
December	15.2	0	2.9

4. ESTIMATION OF IMPACTS

Air quality is determined by a combination of pollutant emissions and atmospheric interaction and its impact is referred to as an impact scenario. In an air quality impact assessment, two types of impact scenario are generally used. The first is the most probable case, which provides the most frequently encountered impact and is a basis for comparison with standards and regulation. The second is the worst case impact scenario which identifies the worst air quality impact. The most probable case is required to evaluate the prevailing air quality impact, whereas the worst case is required to evaluate the maximum impact (Rau and Wooten, 1980).

The most probable impact is estimated by using the model described in Section 2. In order to determine

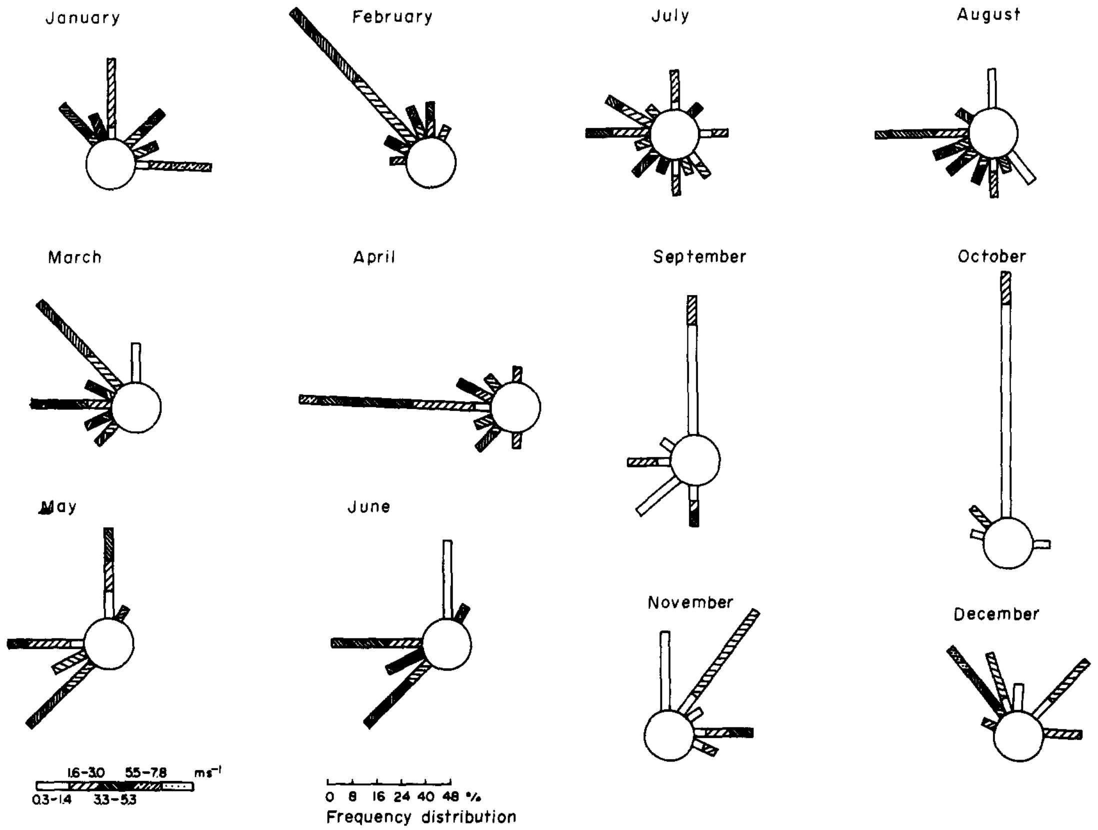

Fig. 2. Wind roses for the 3-day periods in each month of 1983.

the air quality in one month, the concentration is computed at a distance of every 100 m from the power plant to 0.5 km, every 250 m from 0.5 to 2 km and, then in steps of 500 m from 2 km up to the city limit, for 3 consecutive days during the middle of each month of 1983. Although it is recognised that average meteorological conditions during the 3 days may not be representative of the actual condition in a month, it is assumed in the present study that the days selected in the middle of the month may have some representativeness of meteorological conditions in that month. The meteorological data at 8 fixed hours in each day are used. The daily averages thus obtained are summed to get an average and treated as the most probable short-term SO_2 concentration in a month. The same procedure is adopted for all the 16 directions of the compass and for all the months.

The computed concentrations of SO_2 are plotted on a map every 500 m in 16 directions. Zones of sulphur dioxide delineating 20 and multiples of 40 $\mu g\,m^{-3}$ in each month are identified and plotted. For the months April and October, the zones are shown as 20, 40, 80, 120, 200 and 500 $\mu g\,m^{-3}$.

To estimate the worst case impact, emissions being constant, unfavourable atmospheric conditions are assumed, namely inversion condition and fumigation. The SO_2 concentrations are worked out for downwind distances up to 10 km when there is an inversion layer at a height of 500 m and for Pasquill's stability category 'C' in the ground.

5. RESULTS AND DISCUSSION

5.1. *Probable air quality*

The spatial distributions of short-term concentrations of SO_2 from January to December are presented in Figs 3a–3l. The salient features of the figures are summarized in Table 3. The table shows locations and ranges of high zones (km) from the thermal power plant over different areas in different months. Also the computed highest SO_2 concentrations are given in the last column of the table.

According to ambient air quality standards (EPA, 1971), the short-term primary ambient air quality standard for sulphur dioxide is a maximum 24-h concentration of 365 $\mu g\,m^{-3}$ not to be exceeded more than once per year. With a maximum restriction of 365 $\mu g\,m^{-3}$ (24 h), the 4-day average could vary from an estimated 225 to 185 $\mu g\,m^{-3}$. These standards are designed to protect human health.

Thus the 3-day average high zones of sulphur dioxide pollution (40–160 $\mu g\,m^{-3}$) due to the power plant are within the EPA standard (225–185 $\mu g\,m^{-3}$) over the residential, commercial and industrial areas of the city throughout the year except for the months of April and October. In these two months levels of SO_2 (500 $\mu g\,m^{-3}$) are in excess of the EPA standard. According to Guldmann and Shefer (1980), for short exposure to SO_2 the critical concentration is in the range 300–500 $\mu g\,m^{-3}$, as an average daily concentration for 3–4 days. The area (between 1.4 and 2.7 km from the plant) in the eastern direction, where high concentration of SO_2 is observed in April, lies beyond the city limits. The higher value of SO_2 in October (500 $\mu g\,m^{-3}$) is likely to be a cause for considerable discomfort to the people in this zone (between 5.25 and 7.0 km from the plant and could even be detrimental to human health.

5.2. *Air quality in the worst case*

An inversion forms due to cooling of the ground on a clear night. With the appearance of the sun in the morning, convective eddies develop in the boundary layer with the gradual warming of the ground and thus the atmosphere becomes slightly unstable. These eddies move upward and rapidly mix the pollutants while the inversion aloft prevents upward diffusion. This phenomenon, called fumigation, can cause very high concentrations of the effluent in the boundary layer. Hence, the SO_2 concentrations are worked out for downwind distances up to 10 km when there is an inversion layer at a height of 500 m and for Pasquill's stability class 'C' in the ground. Curves A, B and C in Fig. 4 show computed concentrations of SO_2 at different distances from the plant for wind speeds of 2, 3 and 4 $m\,s^{-1}$, respectively. As seen from Fig. 4, the higher concentrations (724 and 900 $\mu g\,m^{-3}$) can occur at distances of 2.5 and 1.5 km from the plant when the wind speed is 2 and 3 $m\,s^{-1}$, respectively (curves A and B). The concentration of SO_2 can reach a peak (992 $\mu g\,m^{-3}$) at a distance of 1.25 km when the wind speed is higher (4 $m\,s^{-1}$) (curve C). In all the three cases (A, B, C) the concentrations of SO_2 have crossed the EPA standard (365 $\mu g\,m^{-3}$, 24-h average). For short exposure (7–8 h), a critical concentration is about 800–1300 $\mu g\,m^{-3}$. With such high levels of SO_2 (724–992 $\mu g\,m^{-3}$) there could be an adverse effect on human health, sensitive plants and visibility. Thus, under trapping and fumigation conditions, the power plant will have a strong impact at distances near to (1.25–2.5 km) the thermal power plant. There is evidence that fumigation during calm conditions may lead to the highest ground-level concentrations at a large power plant (Hosler, 1963).

6. SUMMARY AND CONCLUSION

The present study has suggested the following:

(1) In absence of other pollution sources, the probable zones of high concentration of sulphur dioxide (160 $\mu g\,m^{-3}$) over residential, commercial and industrial areas do not exceed the EPA ambient air quality standards (185–225 $\mu g\,m^{-3}$, the 4-day average) throughout the year except in the months of October and April.

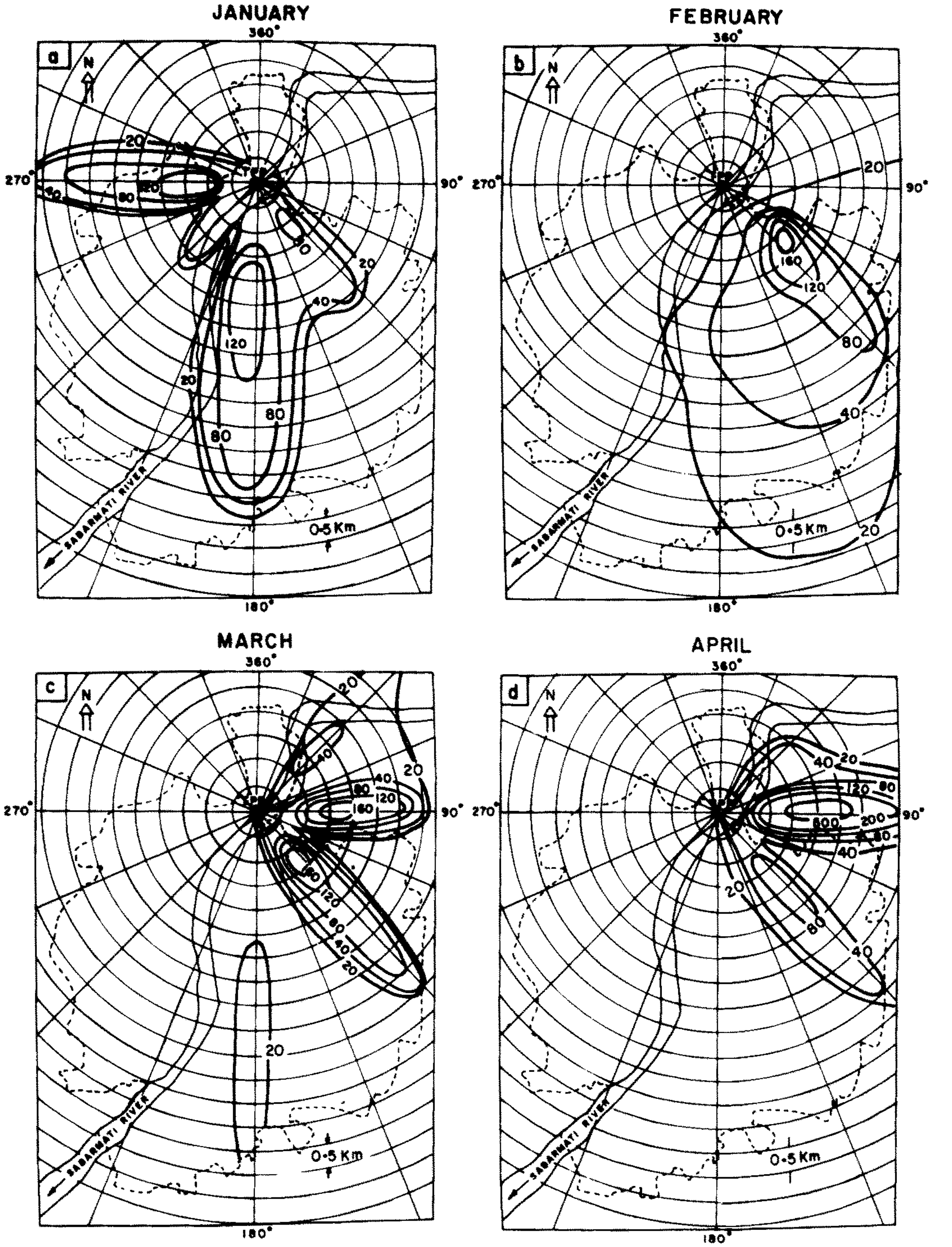
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Fig. 3. (a–d).

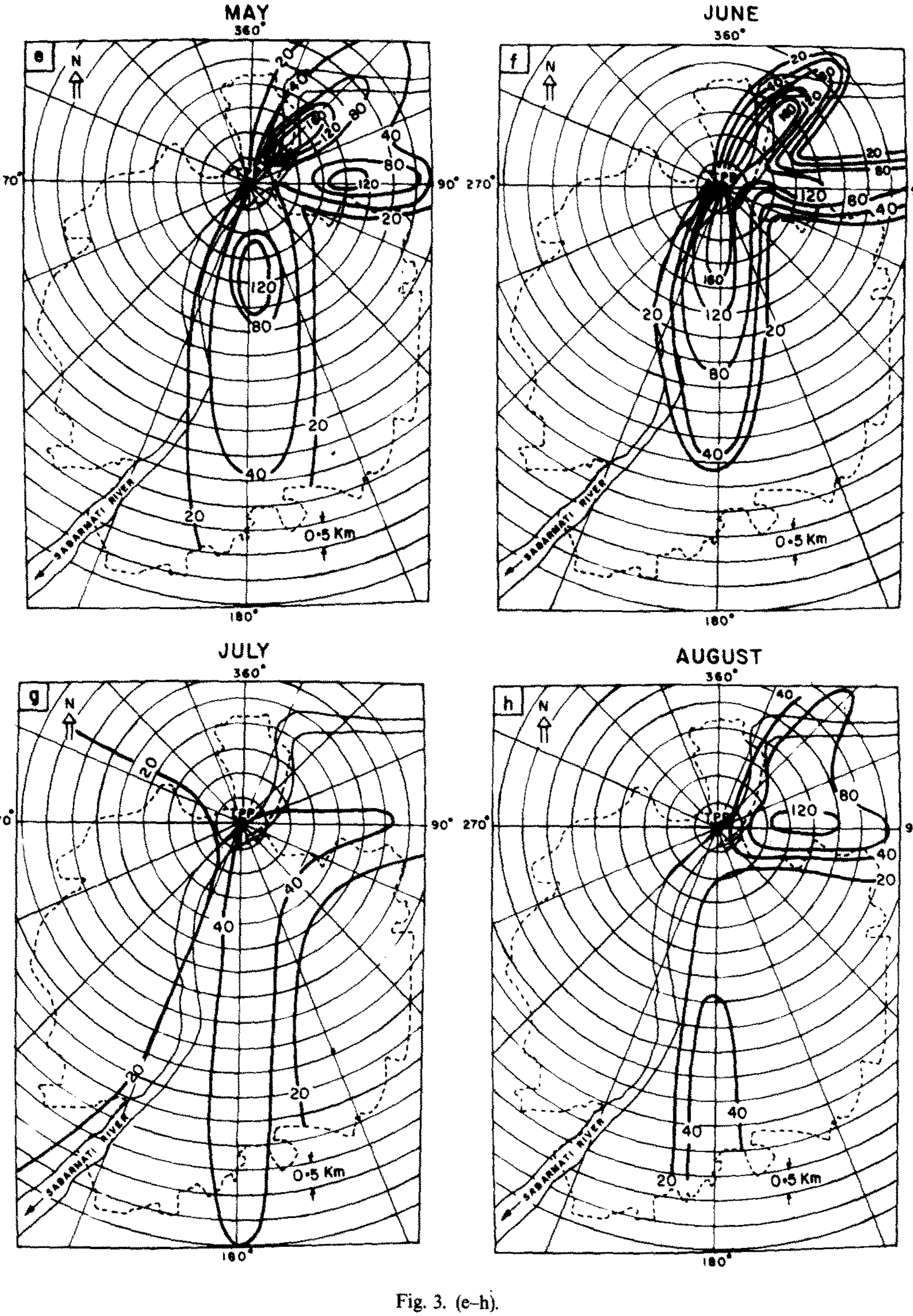
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Fig. 3. (e–h).

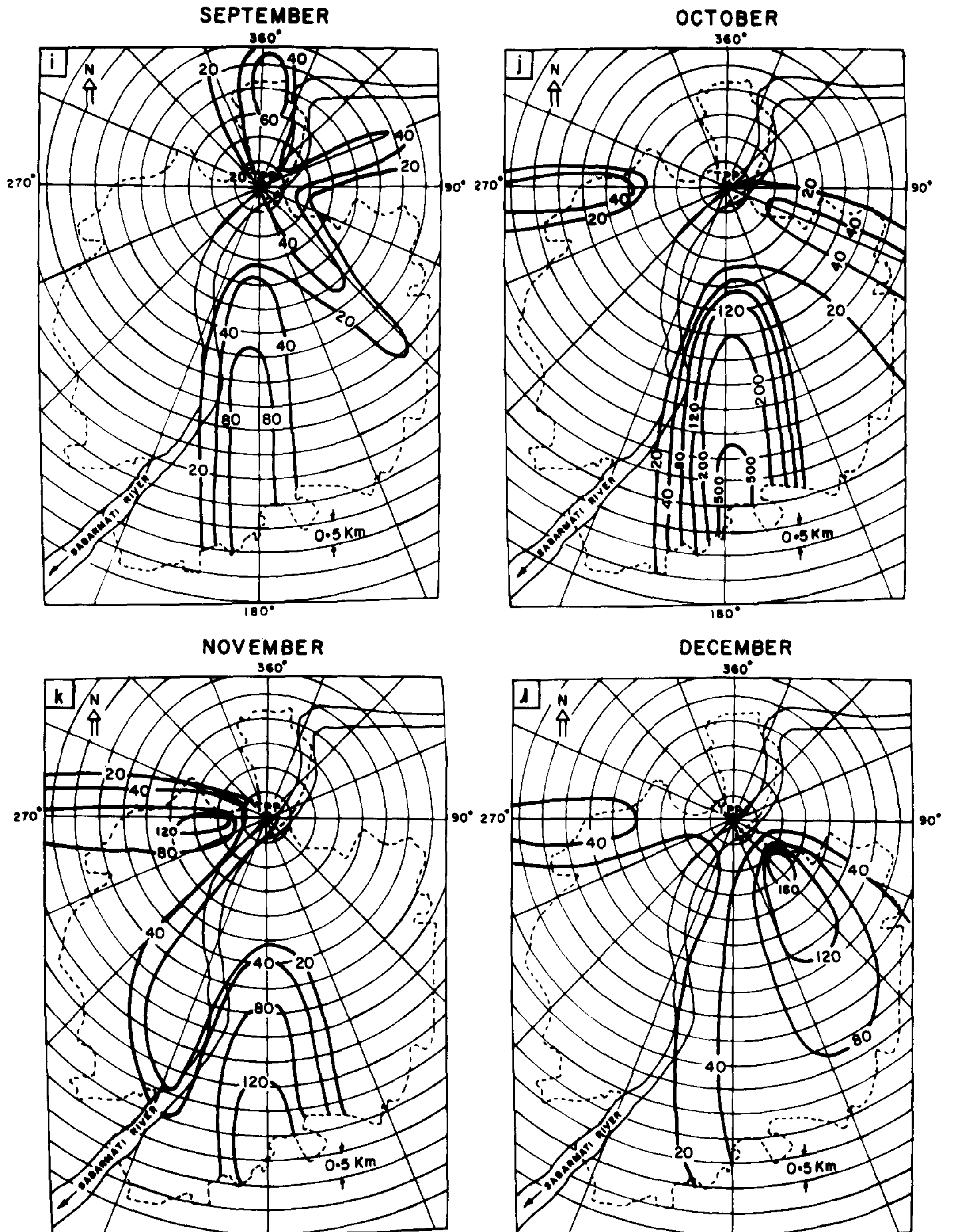

Fig. 3. The most probable distribution of short-term concentration of SO_2 from the thermal power plant from January to December.

(2) In October and April, high concentrations of sulphur dioxide (500 $\mu g\,m^{-3}$) may exceed the EPA standard. The high zone of SO_2 in April lies between 1.4 and 2.7 km from the plant. As the values of concentration can exceed the EPA standard, it is suggested that residential expansion in this area should be minimized. The high concenteration in October which can spread in the area between 5.25 and 7 km from the plant may cause discomfort to the people in the commercial area. Control techniques such as an increase in stack height is suggested which will result in the shifting

Table 3. Locations and ranges of high zones (km) from the thermal power plant over different areas in different months

Month	Area of city* R	C	I	0†	Highest SO_2 concentration ($\mu g\ m^{-3}$)
January	(0.8–2.25)‡	(1.6–4.0)	—	—	120, 120
February	—	—	(1.5–1.9)	—	160
March	—	—	(1.0–1.60)	(1.3–2.0)	160, 160
April	—	—	—	(1.4–2.7)	500
May	—	(1.2–2.6)	—	(0.8–2.0)	120, 160
June	—	(0.0–1.7)	—	(0.0–2.0)	160, 120
July	—	—	—	—	40
August	—	—	—	(1.1–2.5)	20, 120
September	—	—	—	—	80
October	—	(5.25–7.0)	—	—	500
November	(0.8–1.8)	(5.4–7.5)	—	—	120, 120
December	—	—	(1.0–1.75)		160

*R = Residential, C = commercial, I = industrial areas.
†0 = Areas out of city limit.
‡Figures in brackets are distances in km from the power plant.

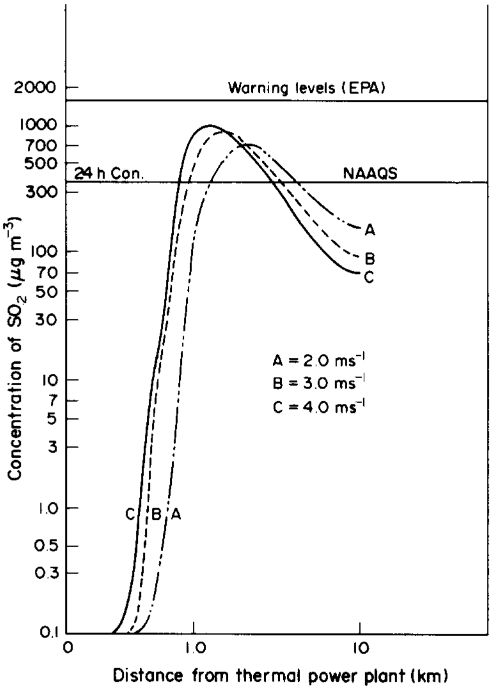

Fig. 4. Computed concentration of SO_2 for downwind distances from the thermal power plant for wind speeds of 2, 3 and 4 $m\,s^{-1}$.

of high zones of SO_2 further downwind beyond the city limit so as to prevent its effect on human beings.

(3) The concentration of sulphur dioxide can reach up to 1000 $\mu g\ m^{-3}$ near the power plant at a distance of 1.25 km under unfavourable meteorological conditions.

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