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Meteorological data requirements for environmental impact assessment

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ABSTRACT. Meteorological data requirements for a quick appraisal as well as a detailed analytical study are identified. Methods of obtaining these parameters either by experimental technique or by theoretical method have been indicated. An example of the differences in concentration computations between quick appraisal and detailed analytical study is also presented and discussed.

1. Introduction

It has been recognised that environmental meteorological support is essential for an impact assessment of pollutants released from either a single source or multiple sources. Often it is impossible to estimate accurately the frequency of occurrence of adverse conditions without local, pertinent meteorological data and this implies a survey based on meteorological records appropriate for the site and problems. The sophistication of the required instrumentation may range from a single wind instrument to an array of sensors measuring several parameters, depending on the terrain and the nature of the problem.

In uncomplicated surroundings and for relatively short distances ($\leqslant$10 km) a modest array of meteorological instruments will usually suffice, but as the environment becomes more complex and as the problem extends to greater distances, one has to rely on a multitude of meteorological instruments or substitute some of the modelling techniques to obtain proper input data (Smith 1968).

2. Need for the study

Increasing industrialisation and consequent urbanization with no regard to the atmospheric characterictics is rendering the ambient air quality at several places deteriorate. Proper air management leading to permissible air quality can be achieved through a meteorological approach utilizing the dilution capacity of the atmosphere to a maximum. The meteorological data needed for quick appraisal of a pollution problem can be dealt with available data collected from conventional instruments. However, for a detailed analytical study sophisticated equipment and techniques are essential. In the present paper the minimum requirements of input meteorological data for quick appraisal as well as a detailed analytical study of the environmental impact assessment are enumerated.

3. Methodology

The ground level short term (1 hour) concentrations from an elevated source are provided by the Gaussian distribution equation :

$$\chi = \frac{Q}{\pi u\, \sigma_y \sigma_z} \exp\left[-\tfrac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{h^2}{\sigma_z^2}\right)\right] \quad (1)$$

where,

χ = Short term (1 hour) ground level concentration (μg/m^3)

Q = Emission rate (μg/s)

Q_H = Emission of heat (mW)

u = Mean wind speed at stack height (m/s)

h = Effective stack height ($H+\triangle h$) (m)

H = Physical stack height (m)

$\triangle h$ = Plume rise (m)

σ_y, σ_z = Standard deviations of plume concentration along y and z (m)

x, y = Distances downwind (x) and cross wind (y) from the stack (m)

Computations of concentrations, therefore, need dispersion characteristics σ_y and σ_z, wind at stack height and plume rise.

4. Source of data

An elevated (80 m) chimney with an emission rate 0.342 ton/hr of sulphur dioxide and heat emission of 65.85 mW is the source in the present study.

The meteorological data input is obtained from conventional cup anemometer (accuracy ±2 km/hr, starting speed 1.2 km/hr) and mercury in glass thermometer (accuracy $\pm 0{\cdot}2$°C, time constant 30-60 sec in wind speed of 5 m/s) or a climatological model.

For detailed analysis dispersion characteristics, wind speeds, and directions were derived from the records of special windvane and anemometer at two levels over mast. Temperatures were recorded by bead thermistors shielded from direct radiation with proper calibration and exposure. Accuracies of wind speed, wind direction and temperature are 1 knot, 5° and 0.15°C respectively. Temperature and wind profiles were also obtained by tethered balloons and special pilot balloon ascents.

5. Dispersion characteristics (σ_y and σ_z)

From the range of wind direction traces the standard deviation of horizontal angle (σ_θ) and corresponding wind speed at two levels were determined according to Slade (1968).

Considering stability classification based on net radiation index and wind speed (Turner 1·970) as standard the wind direction fluctuations (similar to Brookhavan National Laboratory—Slade 1968) were standardized. For each computation of σ_θ

Bulk Richardson number $R_B = \left(\frac{g}{T}\frac{\triangle T}{\triangle z} + \Gamma\right)\frac{z^2}{u^2}$

(where g = acceleration due to gravity, $\triangle T$= temperature difference between top and bottom of the layer of thickness $\triangle z$, T is mean temperature of the layer, z=height of the upper anemometer and u is mean wind speed at the upper level) also was calculated.

In the literature (Smith 1968) it is reported that lateral (σ_v) and vertical (σ_w) components of the winds are approximately constant with height and since $\sigma_v = \sigma_{\theta\bar{u}}$ and $\sigma_w = \sigma_{\theta\bar{u}}$ one can easily make adjustments to the angular standard deviations from $(\sigma_\theta u)_T = (\sigma_\theta u)_G$, where θ refers to horizontal angular fluctuation, G and T refer to ground ($2\frac{1}{2}$ m) and tower ($20\frac{1}{2}$ m) levels. As no windvane or anemometer are available at stack level (80 m) the validity of the above relationship is tested first and then adopted to obtain σ_θ at stack level. These σ_θ values were again standardised with respect to Turner's classification.

6. Winds at stack level

Wind speeds are continuously recorded at $2\frac{1}{2}$ m and $20\frac{1}{2}$ m over a mast. Single theodolite observations of the winds also were made twice daily at 03 and 12GMT. 15-gram balloons were used with flags to the tail at 5, $12\frac{1}{2}$ and 25 m. Free lift tables and other nomograms were modified and observations were taken at every 30 seconds and the flight was abandoned after 3000 m. From the wind profile, winds at intervals of 50 metres from 50 m level upto 300 m were picked up. These speeds with simultaneous winds from the tower are used in deriving the coefficients of power laws. Stability is determined as per Turner's (1964) classification. The power law used in the present study is of the form (Sutton 1953):

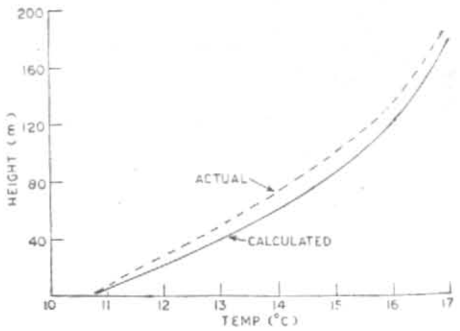

Fig. 1. Comparison of temperature profile for 0030 GMT of 24 Feb 1977 with mathematical model

$$u_2 = u_1 \left(\frac{z_2}{z_1}\right)^p$$

where z and u refer to height and wind speed and 1 and 2 correspond to lower and upper levels. The magnitude of the coefficient for various stabilities are :

$$\begin{aligned} p &= 1/9 \quad \text{(unstable)} \\ &= 1/7 \quad \text{(neutral)} \\ &= 1/3 \quad \text{(stable)} \end{aligned}$$

7. Plume rise

Plume rise can be calculated as a function of source parameters, such as buoyancy and meteorological conditions. Numerous formulae have been reported in literature but hardly any of them agree either with each other or with new observations if they go outside the range of variables of observations the techniques were originally made to fit (Briggs 1975, Guldberg 1975). A comparative study was made of several empirical and semi-empirical formulae and it is found that plume rise as determined by modified Lucas' formulae (Moore 1974) yields reasonably good results. The formula used in the present study is :

$$\triangle h = \frac{(60+5H)}{u} \times Q_H^{0\cdot 25} \quad \text{(Unstable and neutral conditions)}$$

$$\triangle h = \frac{116}{u} \times Q_H^{0\cdot 25} \quad \text{(Stable and low wind speed)}$$

$$\triangle h = \frac{160}{u} \times Q_H^{0\cdot 25} \quad \text{(Stable and high wind speed)}$$

where the symbols denote the same as indicated earlier.

8. Temperature at Stack level

In unstable and neutral conditions air temperature at stack level was obtained by assuming dry

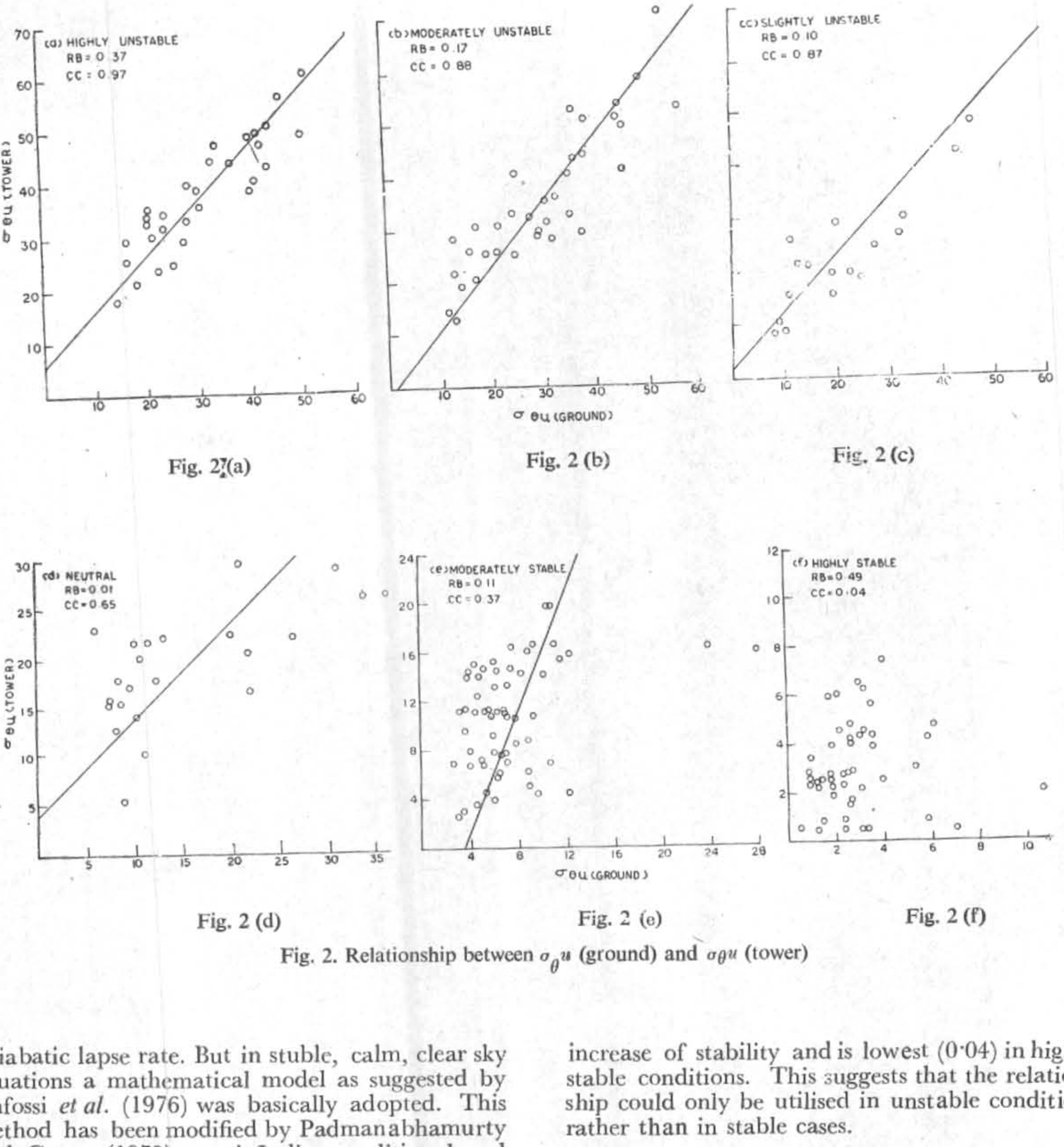

Fig. 2 (a)

Fig. 2 (b)

Fig. 2 (c)

Fig. 2 (d)

Fig. 2 (e)

Fig. 2 (f)

Fig. 2. Relationship between $\sigma_\theta u$ (ground) and $\sigma_\theta u$ (tower)

adiabatic lapse rate. But in stuble, calm, clear sky situations a mathematical model as suggested by Anfossi *et al.* (1976) was basically adopted. This method has been modified by Padmanabhamurty and Gupta (1979) to suit Indian conditions based on the experimental results with tethered balloons. Comparison of the profiles by the model and experiment are shown in Fig. 1.

9. Results

Figs. 2 (a-f) show the relationship between $(\sigma_\theta u)_G$ and $(\sigma_\theta u)_T$ in highly unstable, moderately unstable, slightly unstable, neutral, moderately stable and highly stable cases. Bulk Richardson's number correlation coefficient between $(\sigma_\theta u)_G$ and $(\sigma_\theta u)_T$ slope and intercept in (January, May, July, October) representative months of four seasons are presented in Table 1(a-d). Bulk Richardson number is generally negative in unstable and positive in stable conditions. The correlation coefficient between $(\sigma_\theta u)_G$ and $(\sigma_\theta u)_T$ is highest (0.97) under highly unstable conditions gradually decreased with increase of stability and is lowest (0·04) in highly stable conditions. This suggests that the relationship could only be utilised in unstable conditions rather than in stable cases.

Utilising the above stability classification and Brigg's regression equations for σ_y and σ_z (Gifford 1975) the numerical values of dispersion coefficients are obtained. Plume rise is obtained by modified Lucas' formulae. Wind at stack height was obtained by power laws and temperature at stack height from Stevenson screen.

The concentrations at 40 and 100 km downwind from the stack were obtained using Eqn. (1) and normal data of the station culled out of climatological tables of India Meteorological Department. The maximum short term (1 hour) concentrations at 40 and 100 km downwind considering only 03 and 12 GMT normal data of 12 months are 27.3 $\mu g/m^3$ and 8·67 $\mu g/m^3$ respectively. In these calculations McElroy's (1969) equations for σ_y and σ_z are used. Detailed compu-

TABLE 1

Stability parameters at Mathura

	Unstable			Neutral	Stable	
	Highly	Moderately	Slightly		Moderately	Highly
(a) January 1976						
Bulk Richardson No. (R_B)	—0·37	—0·17	—1·10	—0·01	0·11	0·49
C.C. between $(\sigma_\theta u)_T$ and $(\sigma_\theta u)_G$	0·97	0·88	0·87	0·65	0·37	0·04
Slope (°)	45·9	48·6	49	45	68·6	87·7
Intercept	—5·93	0·87	—0·75	—4·04	3·41	2·68
(b) May 1976						
Bulk Richardson No. (R_B)	—0·08	—0·14	—0·11	—0·01	0·16	0·44
C.C. between $(\sigma\theta u)_T$ and $(\sigma_\theta u)_G$	0·62	0·76	0·87	0·69	0·45	0·56
Slope (°)	63·9	62·0	51·7	37·8	72·8	19·3
Intercept	18·05	12·45	0·80	—12·43	4·51	—3·23
(c) July 1976						
Bulk Richardson No. (R_B)	—0·05	—0·01	0·06	0·02	0·13	0·08
C.C. between $(\sigma_\theta u)_T$ and $(\sigma_\theta u)_G$	—0·25	0·32	0·19	0·32	0·05	—0·01
Slope (°)	..	65·3	75·4	63·4	86·9	—
Intercept	85·30	23·23	21·73	13·10	13·40	11·65
(d) October 1976						
Bulk Richardson No. (R_B)	0·06	—0·11	—0·16	0·23	0·45	0·90
C.C. between $(\sigma_\theta u)_T$ and $(\sigma_\theta u)_G$	0·86	0·95	0·81	0·35	0·46	0·60
Slope (°)	56·4	53·5	50·0	72·3	78·7	11·1
Intercept	6·77	2·26	—2·58	3·23	3·21	—6·66

tations were carried with each hour data using the widely used Brigg's (1974) equations for σ_y and σ_z and the average short term (1 hour) concentrations at 40 and 100 km downwind by using hourly data over an year came out to be 17 $\mu g/m^3$ and 10.9 $\mu g/m^3$. A comparison of the quick appraisal model and detailed anaytical model points out that the former could safely be used for a preliminary advice on stack height and ambient air quality while the latter yields a sophisticated mapping of zones of varying degrees of pollutants to assist the planners in delineating areas for residences shopping centres, ponds, parks, playgrounds, buffer zones etc.

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