

Air pollution climatology of Cochin for pollution management and abatement planning

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सार — वायु प्रदूषकों के विसर्जन एवं मंद होने के साथ साथ उनके संकेंद्रण के बारे में कुछ भी निश्चित करने के लिए वातावरण में व्याप्त मौसम परिस्थितियों का बहुत महत्व है। जिस तरह से तेज़ हवा और मौसम की स्थिरता वायुप्रदूषकों के परस्पर मिलने के लिए बहुत उपयुक्त है उसी तरह से बदलता हुआ मौसम और मंद पवन इनकी संरचना के लिए उपयुक्त हैं। वायुप्रदूषकों के लिए विभिन्न अनुकूल और प्रतिकूल स्थितियों को समझने के लिए भारत के पश्चिमी तट पर स्थित औद्योगिक शहर कोचीन के कुछ वायुमंडलीय पहलुओं का अध्ययन किया गया है।

समुद्र तटीय शहर होने के कारण यहाँ मौसम और तापमान में परिवर्तन अधिक नहीं होते हैं। शहर के दक्षिणी पश्चिमी भागों में पूरे वर्ष सुबह के समय में वायुप्रदूषक कारकों में कम परिवर्तन पाया गया है। कारकों की स्थानीय परिवर्तिता के अध्ययन से पहली बार यह पता चला है कि सामान्य बिन्दु पर इनके प्रेक्षण के एक एकल मान को पूरे शहर के औसत मान के रूप में नहीं माना जा सकता है।

ABSTRACT. The prevailing atmospheric condition is very important in determining the dispersion and dilution and thereby the resulting concentration of air pollutants. While high wind speed and stability conditions in general favour good mixing of air pollutants, conditions like inversion and calm winds cause for the build up of pollutants. In order to understand the different favourable and unfavourable conditions, some of the atmospheric aspects of air pollution are studied for the industrial city Cochin, situated on the west coast of India.

Being a coastal city, the frequency of occurrence of inversions and isothermal is not very high. Low values of mixing heights are observed in the southwest parts of the city during early morning hours. The study of spatial variation of mixing heights has revealed for the first time, that a single value of mixing height at the normal point of observation cannot be taken as a representative value for the whole city.

Key words — Inversion, Isothermal, Mixing height & Ventilation coefficient.

1. Introduction

Air pollution climatology is concerned with the aggregate of weather conditions which play an important role in determining the concentration of pollutants in the atmosphere. Effective air pollution warnings can be issued through meteorological forecasts from which abatement strategy can be worked out. The pollutant concentration increases when the atmosphere is unable to adequately dilute the pollutants both vertically and horizontally. In the present paper, the various dispersion parameters such as inversions, isothermals, wind speed and direction, mixing heights and ventilation coefficients are studied for the four different seasons of Cochin namely winter, pre-monsoon, monsoon and post-monsoon.

The increase of temperature with height, known as inversion and the nearly constant temperature with height, known as isothermal are important atmospheric conditions as far as air pollution is considered. Both these atmospheric conditions inhibit vertical mixing of pollutants. The climatology of wind speed and direction of any urban area is an essential first step to be determined for an effective environmental and urban planning. Designing the buildings, location of industrial and residential sectors are dependent primarily on the climatology of wind. The mixing height (MH) is defined as the top of a surface based layer in which vertical mixing is relatively vigorous and in which the lapse rate is approximately dry adiabatic. Ventilation coefficient (VC) is defined as the product of MH and mean wind speed through the mixing layer. This gives an idea of horizontal

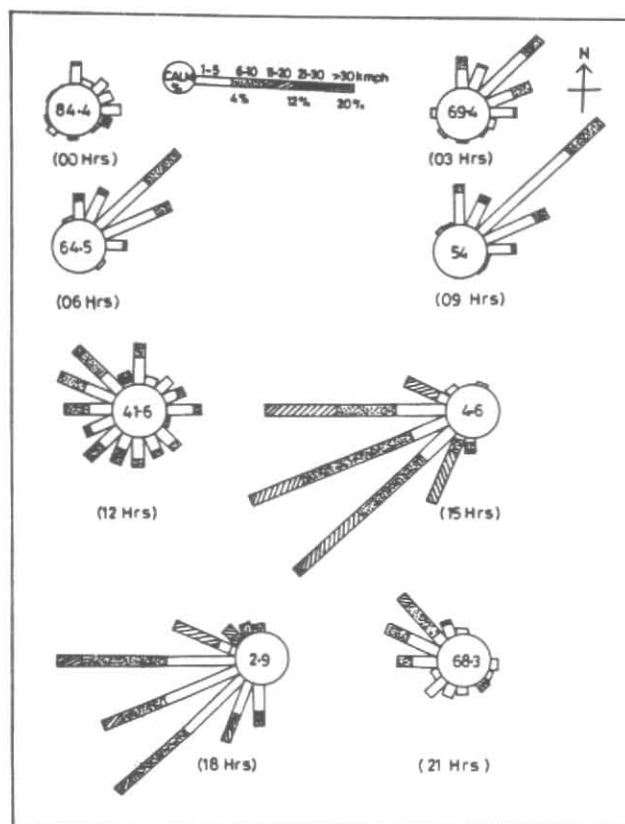


Fig. 1. Wind roses over Cochin for January

transport whereas MH indicates the vertical extent of mixing of pollutants.

2. Data

Upper air data for both morning (0530 hr IST) and evening (1730 hr IST) and maximum and minimum temperatures are collected for ten years from 1973 to 1982. Hourly surface wind speed and direction and surface temperature are also collected for the same period. The source of data is India Meteorological Department (IMD).

3. Methodology

3.1. Inversion and isothermals

The surface based and elevated inversions and the isothermal conditions are noted from the radiosonde data for each month and the frequencies are computed and presented in Table 1. Most of the ground based inversions (GI) and isothermals (IS) reach beyond 100m and their intensities are designated as temperature difference between ground and 100m level. Inversions and isothermal whose base do not start from ground level but extend well above 100m are

considered as elevated inversions (EI) and elevated isothermal (EIS) and they are observed from a height of 100m. The intensity of inversions is in 3 classes, namely $<2^{\circ}\text{C}$, $2 - 4^{\circ}\text{C}$ and $4-6^{\circ}\text{C}$.

3.2. Wind speed and direction

From the hourly wind data, tabulations have been made and frequencies computed for a given month and time, of the occurrence of each of the 16 wind directions, namely N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, NNW in different speed intervals of 1-5, 6-10, 11-20, 21-30, 31-40 and $>40\text{km/hr}$. Speeds less than 1 km are treated as calm conditions and accordingly their frequency has also been computed. Wind roses have been drawn for every three hour intervals for January, April, July and October, which are representative of winter, pre-monsoon, monsoon and post-monsoon seasons respectively.

3.3. Mixing heights and ventilation coefficients

Mixing heights (MHs) have been computed by extending a dry adiabat from the surface temperature to its intersection with the early morning temperature soundings (Holtzworth, 1964). For studying the spatial variation of

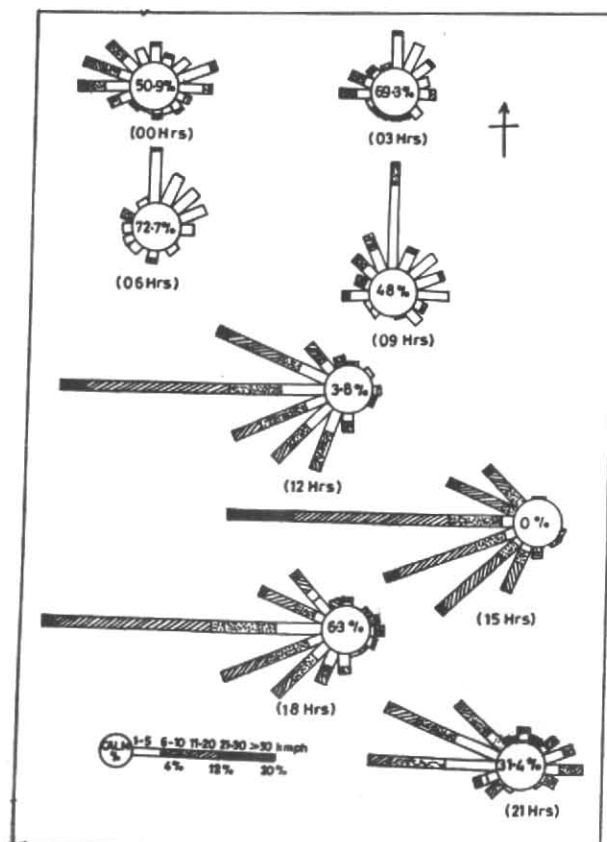


Fig. 2. Wind roses over Cochin for April

MH, the surface temperature values are noted from nine different points in the city. In order to compensate for the urban heat effect, the following method was adopted.

Hourly surface temperature observations from nine points were made during the winter period in 1981 and 1982. The difference in temperature at each of the nine points in the city and at every hour from the corresponding value at the airport are noted and the same difference in temperature are made use of to get the spatial temperature variation for the other months. This approximation at the first instance may appear to be crude, but certainly it is relatively better approximation than that obtained from the empirical methods because it has some experimental evidence. In the absence of a good observational network of surface temperature observations within a given city, this can serve the purpose in a better way.

Accordingly MH is computed with Holzworth methodology for each of the nine points in the city. The monthly means for every three hours are obtained for each of the representative months and the isolines of MH are drawn on the map of Cochin.

Ventilation coefficients (VCs) at any time can be obtained by multiplying the MH at that time with the mean wind speed through the mixing layer. Since the vertical structure of winds at all places where the MH are computed were not available, the surface wind which is available at the place of regular observation site is multiplied with the mean MH to get VC. Mean MH is necessary because the MH at a single point cannot be a representative value for the whole city. The average of MHs at all the nine points in the city gives the mean MH.

4. Results and discussion

4.1. Inversions and isothermal

The percentage frequency of GI, EI and IS for each month are given in Table. 1. Mostly the intensity of inversion is 2°C . GI frequency is maximum in January and less than 1% in May, August and October. However, even the maximum in January shows on an average, only two days with GI. On the other hand the frequency of occurrence of IS is higher. IS frequency minimum is 16.9% and the maximum is 31.3%. Irrespective of the season, IS are present in

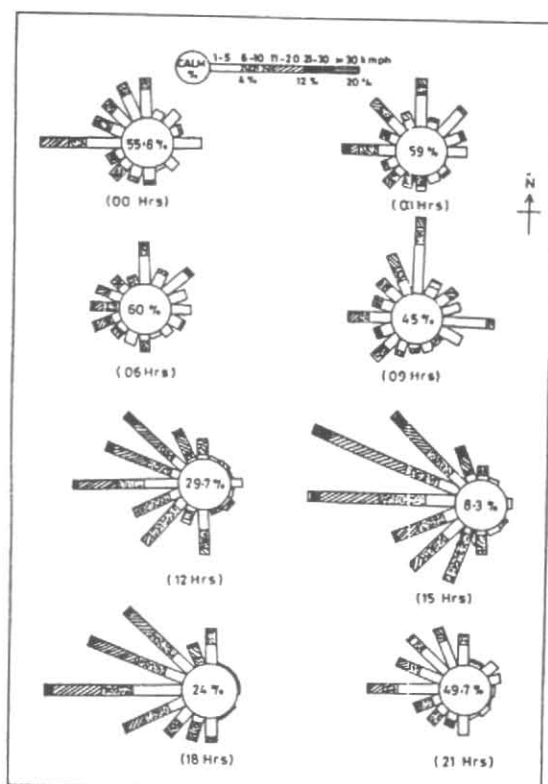


Fig. 3. Wind roses over Cochin for July

considerable frequency, maximum in July and minimum in February.

Cochin being a coastal station, both GI and EI are in negligible quantities when compared with that of inland stations. This fact enables the use of Holzworth method of computing MH in an effective way for this city. If isothermal are combined with inversion frequency, then the occurrence of inversions is seen in considerable frequencies. The non availability of the data for every hundred meters up to 1km may have masked the EIs. However, in the absence of any such information, the observed situation is not very serious as far as air pollution dispersion is concerned.

4.2. Wind speed and direction

Figs. 1 to 4 show the three hourly wind roses for January, April, July and October. In January, calm conditions were persisting from 2100 to 0900 hrs (IST) with a maximum of nearly 85% at midnight. The wind direction is NE during night time. At 1200 hrs (IST) the winds are relatively stronger and are almost uniformly distributed in all directions. At 1500 and 1800 hrs (IST) the prominent wind directions are from southwest sector. The maximum wind speed was recorded at these two timings.

In April, the wind direction is slightly different from that observed in January. There is no predominance of NE winds during night time. Northerly wind prevails slightly at 0300 hrs (IST) and reaches maximum at 0900 hrs (IST). At 1200 hrs (IST) one can see the W dominating with components from southwest and north-northwest sectors. Strong westerlies with speeds ranging from 21 to 30 km/hr are noticed at 1500 hrs (IST). The winds from west and north-west continued considerably during evening hours. Calm conditions were persisting more from midnight to 0900 hrs (IST).

From 2100 to 0900 hrs (IST) in July, again the calm conditions were persisting more. There is no persistent wind direction during this period but the winds are strong even if the percentage of occurrence of the wind directions is small. Prominent wind direction at the other times are W and NW. There is a considerable frequency from southwest direction also. The winds are strongest in this month ranging to more than 30 km/hr.

In October also calm conditions were prevailing from 2100 to 0900 hrs (IST). The winds are either E or NE during this period. For the rest of the period, W or SW are predominant.

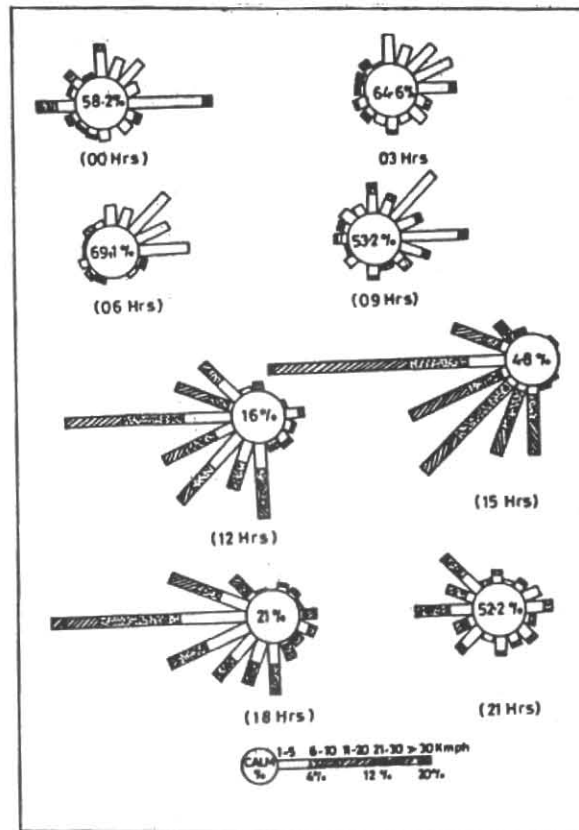


Fig. 4. Wind roses over Cochin for October

It will be of interest to know the wind pattern during the occurrence of inversion. GI, even though not much in frequency, occur mostly in winter months as that can be expected. Fog, sometimes experienced in the region during early morning hours, indicates the presence of the inversion during night hours. From the wind roses, it can be seen that during night hours light winds prevail from north or northeast direction in Cochin.

4.3. Mixing height and ventilation coefficient

Figs. 6 to 9 depict the spatial distribution of MHs for 0000, 0600, 1200 and 1800 hrs (IST) respectively for January, April, July and October.

Enormous gradients in MHs are noticed at 0000 and 0600 hrs (IST) at the central parts of the city in January. They decrease as one moves towards north or northeast except at 1800 hrs (IST) when they increase towards north. Relatively higher values are observed in the east-southeast portions at 1200 hrs (IST), while the converse appears to be true for the other timings. The southwest portions have shown maximum values and northeast portions minimum at 1200 hrs (IST), while the pattern is different at other timings. For example, at 1800 hrs (IST), higher values in the northeast

and minimum in the southwest portion are noticed with a small cell of maximum in the western portion. At 0600 hrs (IST), the entire southern parts of the city have shown very low values (<100m).

In April at 1200 hrs (IST), the southern parts have shown maximum values and the northeast parts have shown the minimum values. Mostly in the central parts, MH varied between 1.2 and 1.3 km. The spatial range is maximum at 0600 hrs (IST) followed by 1200, 0000 and 1800 hrs (IST). The maximum range is of the order of little over 600 meters.

The maximum values are observed in the central parts at 0000 and 0600 hrs (IST), in the western parts at 1800 hrs (IST) and in the southwestern parts at 1200 hrs (IST) in July. The spatial range is maximum, once again at 1200 hrs (IST). The spatial range is same at the remaining hrs. The extreme southern parts have once again shown minimum values except at 1200 hrs (IST).

In October at 0000 and 0600 hrs (IST), the maximum values are observed in the central parts. The values increased from northern parts to the southern parts of the city at 1200 hrs (IST). However, except at 1200 hrs (IST), the southern portions have shown the lower values in this month also.

TABLE 1
Percent frequency of occurrence of inversions and isothermals over Cochin

Type of inversion	Intensity of inversion (°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Surface based inversion	0°-2°	7.1	4.1	2.6	3.7	0.6	1.3	1.3	0.3	1.0	0.3	2.0	4.0
	2°-4°	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
	4°-6°	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Elevated inversion	0°-2°	1.3	0.0	0.6	0.3	0.3	0.3	1.0	0.6	1.0	0.0	0.0	1.3
	2°-4°	0.3	0.7	0.0	0.6	0.0	0.7	0.0	0.0	0.0	0.3	0.0	0.0
	4°-6°	0.6	0.7	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isothermal	Surface based	28.1	16.9	21.0	23.5	21.9	22.0	31.3	23.9	19.7	25.2	29.3	25.2
	Elevated	1.0	3.1	4.2	4.2	4.5	4.0	4.8	2.6	2.3	4.2	4.7	3.2

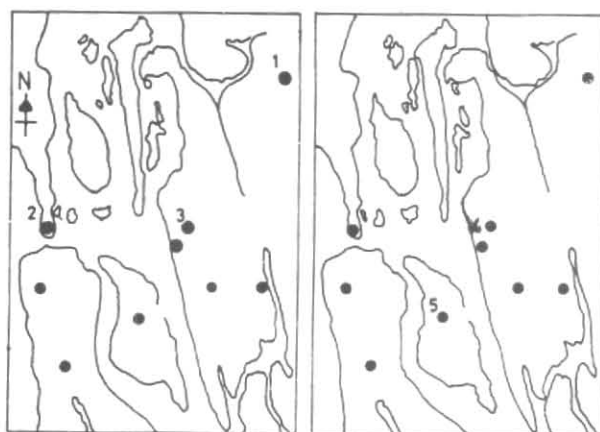


Fig. 5. Map of Cochin showing the points of observation at:

- (1) Trikkakara (2) Vypeen (3) Kacherippady (4) Menaka (5) Naval base (6) Tripunithura (7) Valanjambalam (8) Fort Cochin and (9) Mattanchery

The monthly variation of VC at 0000, 0600, 1200 and 1800 hrs (IST) is depicted in Fig. 10. The monthly variation is not well marked at 0000, 0600 hrs (IST) while, consider-

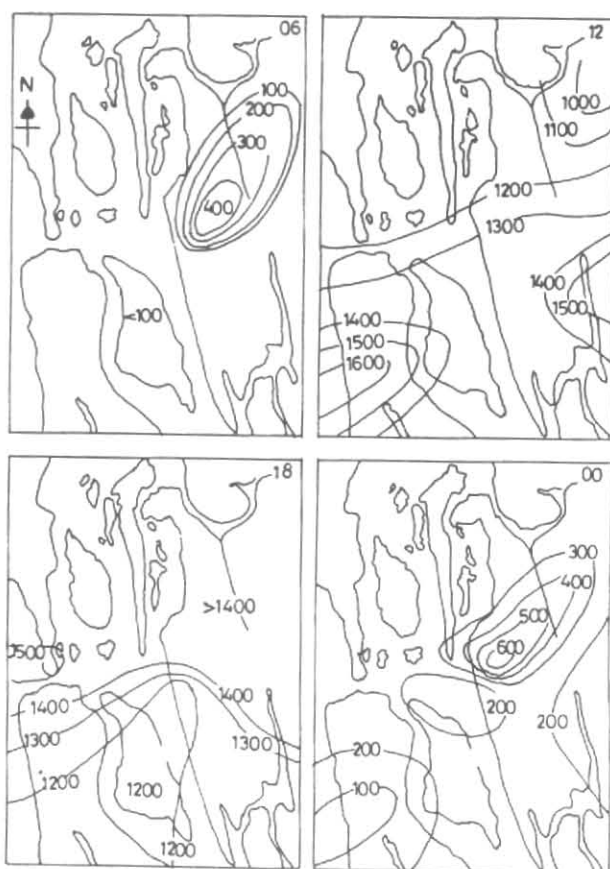


Fig. 6. Spatial variation of mixing height in meters at 0000, 0600, 1200 and 1800 hrs (IST) in January

able variation is observed at 1200 and 1800 hrs (IST). At 1200 hrs (IST) it increases from January to April, July to September, November to December and decreases from April to July and September to November. At 1800 hrs (IST) the values are high till May and low from June to December.

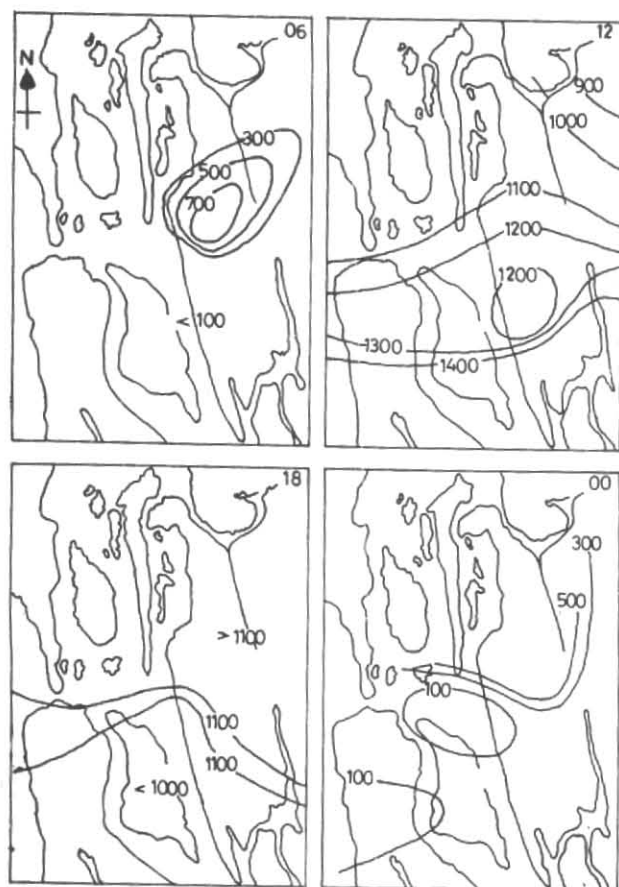


Fig. 7. Spatial variation of mixing height in meters at 0000, 0600, 1200 and 1800 hrs (IST) in April. (Isoleths are in 200m intervals at 0000 and 0600 hrs (IST))

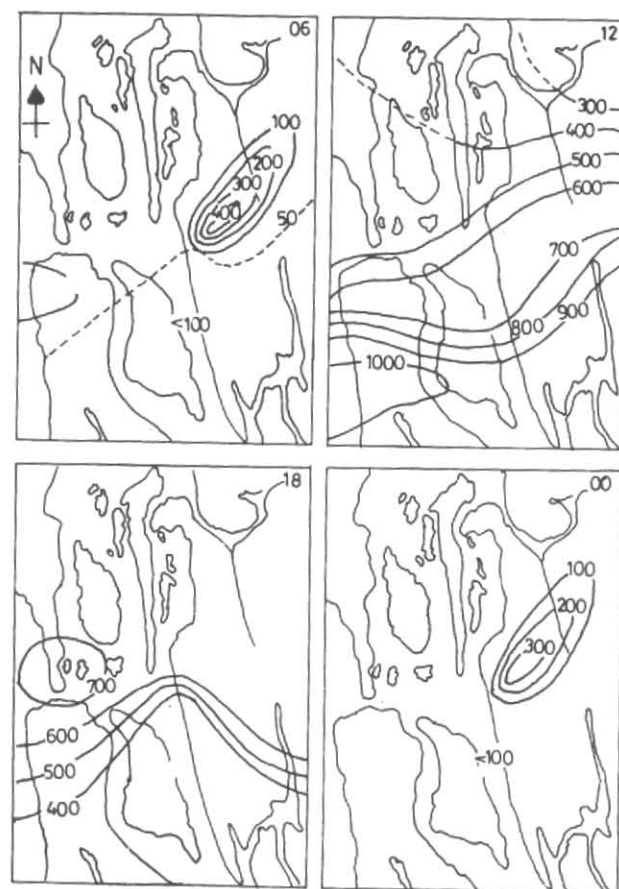


Fig. 8. Spatial variation of mixing height in meters at 0000, 0600, 1200 and 1800 hrs (IST) in July

The maximum VC is observed in February, the secondary peak in April. However the values did not exceed $6000 \text{ m}^2/\text{s}$, an optimum value suggested for good dispersal of pollutants by U.S., E.P.A. The low value may be due to the fact that only surface wind is used instead of the vertically averaged wind through the mixing layer. An attempt has been made to compute the VC by considering the mean of the vertical wind throughout the mixing column by making use of past upper air data. This has been done in the case of 1800 hrs (IST) values since the afternoon upper air data was only available.

5. Conclusion

The study of inversions revealed that Cochin being a coastal station, the percentage frequency of occurrence of inversions and isothermal is low in all months compared to that of inland stations, Even those inversions which are present do not have much intensity. The non availability of

the data for every hundred meters up to 1 km may have masked the elevated inversions. In the absence of any such information it is to be concluded that the situation was not very serious as far as air pollution dispersion is concerned.

Relatively more calm frequency and light winds during night and strong winds during day time are the salient features that the study of wind roses has revealed. During most of the time of the year, W during day time and NE during night time are the dominant winds. The winds are strongest in July followed by April, October and January. The diurnal variation is maximum in July. E or NE during night time and W or SW during day time is an indication of the presence of mesoscale circulation in Cochin.

The spatial variation of MHs within Cochin revealed that a single MH at the normal point of observation cannot be taken to be representative for the whole city in view of its very wide spatial variation (Anil Kumar 1986). There appears to be every possibility for the build up of air pollutants in the south-southwestern parts, especially during

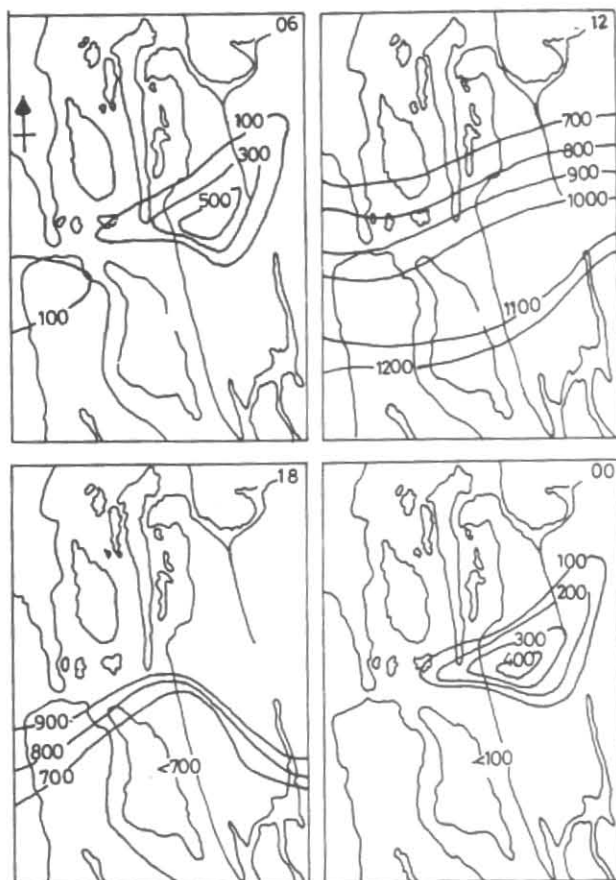


Fig. 9. Spatial variation of mixing height in meters at 0000, 0600, 1200 and 1800 hrs (IST) in October, (Isopleths are in 200m intervals at 0600 hrs (IST))

night time because of very low MHs. Southern portions of the city can perhaps be treated as suburban areas and are very close to the water bodies, which may explain the extremely

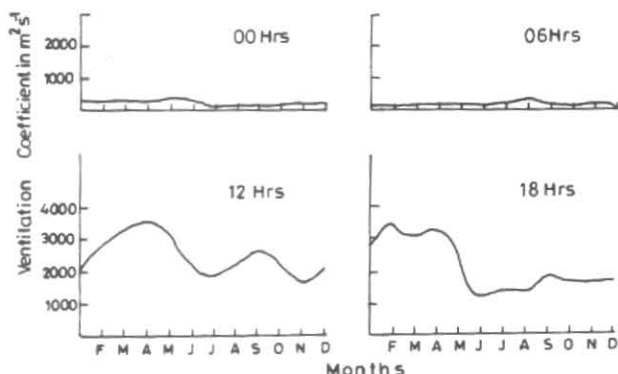


Fig. 10. Monthly variation of Ventilation coefficients at 0000, 0600, 1200 and 1800 (IST)

low mixing during night time and relatively low mixing during day time. However, at 1200 hrs (IST), the southwestern portions are showing higher values because in the Mattancherry area, the effect of land of that huge island is felt more.

The study of VC revealed that afternoon coefficients values in Cochin increased from January to April and decreased considerably and is minimum in August and increased thereafter. The months with higher values of VCs are favourable for rapid dispersal of pollutants and emission schedule can be planned accordingly.

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