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Climatological analysis to determine air pollution potential for different zones in India

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Abstract

India is a tropical country extending from 69°E to 95°E and 7°N to 35°N. The country due to its large size experiences multiplicity of climatological conditions depending upon latitude, longitude, topography and proximity to the sea. Hence, the need arises for analyzing the different climatogical zones from point of view of estimating air potential of each typical region. This would assist regulatory bodies, planners and developers in formulation of air pollution management strategies at national and regional levels.

The temperature lapse rate of the atmosphere is an important climatological parameter and is an actual measure of atmospheric thermal stability or instability. Prevailing Mixing Heights, Ventilation Index, Air Pollution Potential Index for determining the dilution capacity or the assimilative capacity of the atmosphere at any location can be derived based on lapse rate measurements. High resolution temperature profile data were obtained by slow ascent balloons (balloon borne minisonde ascents) at various places in India. The environmental lapse rate was monitored periodically during day and night times to estimate the diurnal variation of the lapse rate. The balloons were tracked by optical theodolite in order to obtain vertical wind profiles.

The data obtained has been analyzed to determine mixing heights, its diurnal nature, ground based inversion depths, and elevated inversion heights. The Ventilation Coefficient and Air Pollution Potential Index was also determined.

Mapping of these parameters for the entire country has been done. On the basis of these isoplots one can identify three different regions, viz.(i) Coastal (ii) Landlocked interior and (iii) Hilly / Mountainous. Dispersion modeling for air pollution emissions can be done for these delineated zones. Thus, national regulatory bodies and planners can ascertain the assimilative capacity of the atmosphere as a function of the climatology of the site.

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1 Introduction

The air quality of any place varies from time to time though the emissions may not undergo many variations. This is because air quality strongly depends on the dynamics of the atmosphere and meteorological conditions play a vital role in governing the fate of air pollutants. Once the pollutants are emitted into the atmosphere the amount of air available for dilution is primarily a function of wind speed, and the vertical temperature profile. Transportation is through the action of mean wind, which carries the pollutants away from the source, and the vertical temperature gradient is the driving force for convective mixing i.e. turbulent convective diffusion. The extent of vertical mixing of pollutants is represented by the mixing height parameter.

Mixing Height is important from point of view of its role in dispersion models as well as climatological analysis. From climatological point of view, detailed statistical analysis of mixing heights is useful for forecasting adverse atmospheric conditions and for correlating with ground level concentrations[1] (Holzworth, 1967). It is that quantitative parameter which is a measure of the thickness of the layer of air near the earth's surface within which turbulence and convective mixing takes place. The product of the mixing depth/height and the average wind speed (m/s) within the mixing layer is used as an indicator of the atmospheres dispersive capability. This product is known as the Ventilation Coefficient(m^2/s). Air Pollution Potential is inversely proportional to this product.

Air pollution potential can be characterized by an index that is defined as the inability of the atmosphere to disperse and dilute the pollutants emitted into it and represents the assimilative capacity of the atmosphere. Higher values of this index are indicative of conditions that are unfavorable to the dilution and dispersion of pollutants[2] (Vittalmurthy,1984). It can be used as a management tool for landuse planning and site selection for new and upcoming industries. As the vertical extent of dispersion is also governed by this index, it can be used for designing mitigation measures like optimal height of stack such that ground level concentrations are minimum. Analysis of such a parameter helps in forecasting adverse atmospheric conditions such as stagnation and hence helps in giving a forewarning to avoid air pollution episodes[3] (Holzworth, 1971).

There is considerable uncertainty in our knowledge of the role of meteorological parameters and climatological conditions in determining air pollution potential of the atmosphere. Hence these parameters like mixing height and ventilation coefficients for different regions in India have been presented here in an effort to build up a data-bank of diffusion climatology in the country.

2 Mixing height analysis

The trends in the values of mixing height have been analyzed for the country in order to get an overview of the dispersion capability of the various regions. Generally, radiosonde data, which is easily available from the local meteorological department, are used for this purpose. Radiosonde data is helpful in presenting the long-term trends in mixing height[4](Maske, 1981) whereas higher resolution minisonde temperature profiles are useful for estimating site and time specific mixing height[5](Marsik., 1995). In this study, data obtained from both radiosonde and minisonde have been compared for the analysis of air pollution potential.

2.1 Radiosonde results

Based on radiosonde station data at two synoptic times 00 and 1200 GMT, seasonal and annual spatial variations of mean mixing height were worked out. Mixing heights are highest in premonsoon and lowest in monsoon season. They increased in the post monsoon season to decrease again in winter but winter magnitudes are still higher than monsoon season. The zone of high mixing heights lies in the central parts of northern India except in winter when it is shifted to northern part of the Deccan plateau. The annual distribution indicates a zone of large mixing heights in the central part of the country and low values on the West Coast.

In January month (Fig 1), typical of winter, mean maximum mixing height or Afternoon Mixing Height(AMH) varied from 800 to 2500 m over the whole country. The highest value is 2200 m over central part of the country and the lowest is 800 m or even less over the northern part of the country. In coastal region it ranged from 1200-1400 m whereas, in inland southern zones it varied from 1400 to 2000 m. During April, typical of the premonsoon, afternoon mixing height recorded maximum values. The values were low in the south central part of the country. The higher values in central, eastern and western parts of the country may be explained by maximum incoming solar radiation during April.

In July, typical of the monsoon, mixing depth is much less than April. The values ranged from 800 to 1800 m. In central and western part of the country it ranged from 1400-1800 m. However, in southwest coastal region afternoon mixing height varied between 800-1000 m. The southeast coastal region and southwest coastal region recorded higher AMH. In October, typical of post monsoon, the values ranged from 800-2400 m and decreased from west to east. Higher values were recorded in the north-western region with relatively lower values in the north-east and south-west region. AMH in the central and western region of the country were in the range of 1400-2400m. The magnitude of AMH was found less than 1400 m in the northeastern region of the country, whereas in the coastal region it varies from 1000-1200 m.

Annual trend of mean maximum mixing height (Fig 2) indicates that higher values occur in the central India, whereas minimum in coastal, north and northeast India. The magnitude of AMH varied from 1800-2200 m in central and western part of the country. In inland southern region AMH ranged from 1600-2000 m, whereas, in coastal, northern and north-eastern region of the country it was found less than 1600 m. In general the central part showed larger value of AMH which decrease as one moves towards either of the coasts. As expected, premonsoon recorded higher values over land region followed by post monsoon, winter and monsoon. The coastal region, however showed a different trend by recording higher values in winter followed by premonsoon, monsoon and postmonsoon. The mean range of AMH between interior and the coasts has found to be maximum in premonsoon followed by monsoon, post monsoon and

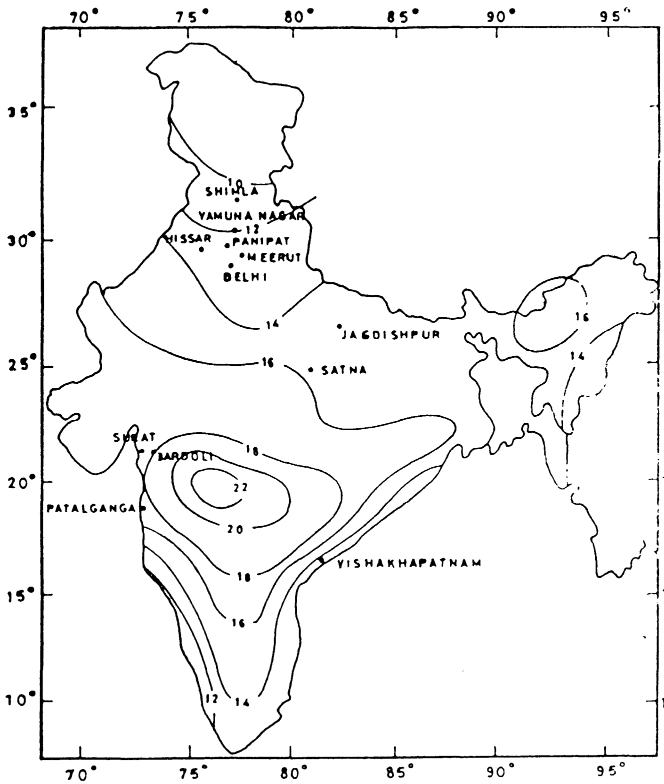

Fig. 1 : Isopleths for Mixing Height (10^2 m) for Winter Season

• MONITORING STATIONS (MINISONDE)

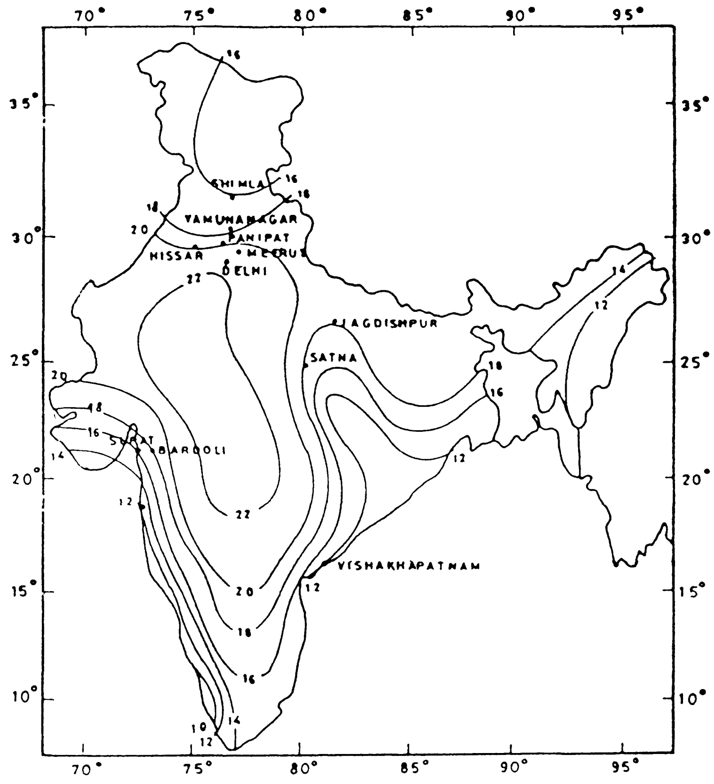

Fig. 2 : Isopleths for Mixing Height (10^2 m) showing Annual Trend

winter. East Coast of India recorded relatively higher values of AMH compared to West Coast of India in post monsoon and monsoon.

2.2 Minisonde results

Lapse rate measurements for 12 sites in India were made using minisonde system to accomplish the objective of studying the diurnal variation of mixing height, wind speed and ventilation coefficient and hence the assimilative capacity profile. The various sites can been broadly classified into three regions as per the geography as follows.

Coastal	Inland	Mountainous
Patalganga	Jagdishpur	Shimla
Vishakhapatnam	Satna	Dharlaghat
	Delhi	Hissar
	Panipat	Yamunanagar
	Surat	
	Bardoli	

2.2.1 Coastal

Diurnal variation in mixing height as recorded (during Winter by 17 minisonde balloon flights) at Patalganga coastal site showed a maximum of nearly 2000 m at around 1.30 p.m in the afternoon (Fig 3). Ground based inversion existed at all other times of the day showing coastal thermal inversion effect.

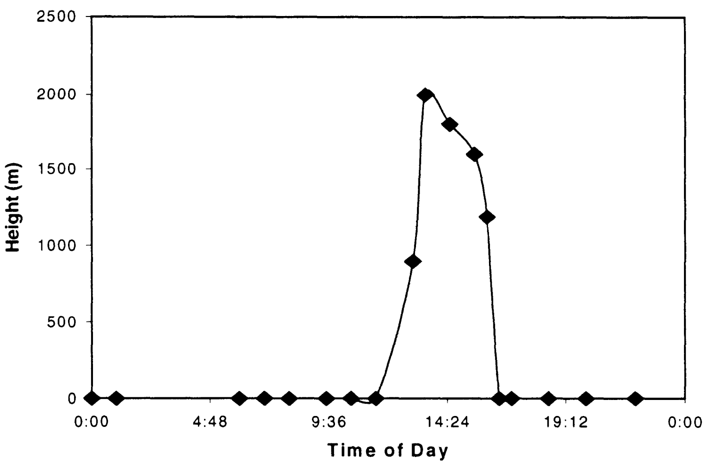

Fig 3 :Diurnal Variation of Mixing Height at Patalganga for Winter Season

2.2.2 Inland

As a case study, analysis of minisonde data for Jagdishpur for two seasons is presented. Jagdishpur is situated in Sultanpur district, 26.5°N and 81.5°E, and lies within the landlocked fertile Gangetic plains of Northern India.

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The diurnal variation of mixing height for two seasons has been plotted in Fig 4. One can immediately observe the difference in summer and winter atmospheric conditions. In summer the area under the curve is larger than that in winter indicating that insolation affects vertical convection. In summer early sunrise and late sunset causes the earth to be heated up for a longer duration as compared to winter. Thus break-up of inversion occurs in the early morning hours (5.00 am) whereas in winter inversion is broken around 8.00 am. Moreover the strength and depth of inversion is greater in winter which takes a longer time to break. Ground based inversion conditions feature predominantly in winter.

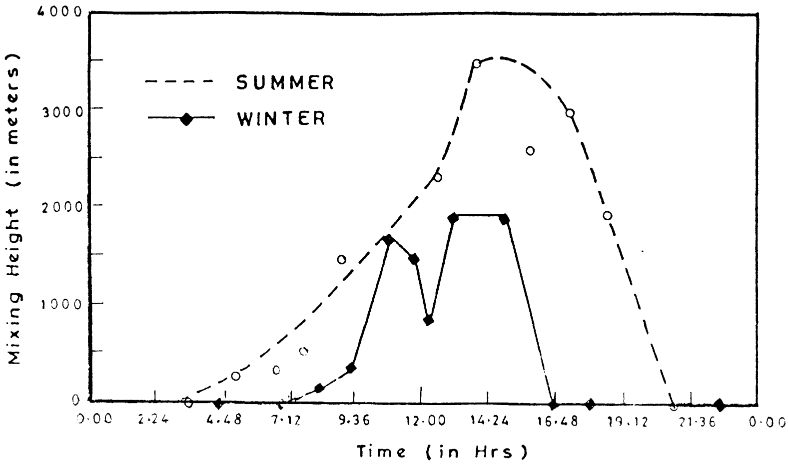

Fig 4: Diurnal Variation of Mixing Height at Jagdishpur for Winter and Summer Seasons

Table 1:Comparison of radiosonde and minisonde results for Jagdishpur
Site : Jagdishpur 26.5°N 81.5°E (78 kms away from Lucknow)
IMD Station : Lucknow 26.75°N 80.88°E

	Minisonde Data			Radiosonde Data		
Season	Average wind speed (m/s)	Max. Mixing Height	Ventilation Coefficient (m^2/s)	Average wind speed (m/s)	Max. Mixing Height	Ventilation Coefficient (m^2/s)
Summer	3.02	3500	9060	5	1400	7000
Winter	0.92	1920	1766.4	3.33	1200	4000

Table 1 compares for the site the IMD radiosonde results with the minisonde values for mixing height, average mixing layer wind speeds and ventilation coefficient. There is a clear disagreement between the two sets of data. The reasons for disagreement may be attributed to the fact that the mixing height, wind speeds, ventilation coefficient data are highly site specific and therefore extrapolation of IMD data over large distances may not be accurate.

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Minisonde balloon soundings were carried out on site , whereas the radiosonde data was procured from the nearest meteorological station situated at Lucknow which is 78 kms from Jagdishpur.

The values of ventilation coefficient for summer are favorable for dispersion of pollutants. But the winter season values for ventilation coefficient are alarming and are highly unfavorable.

2.2.3 Hilly

Mininisonde balloon flights for Shimla were recorded. The data obtained is plotted in **Fig 5**

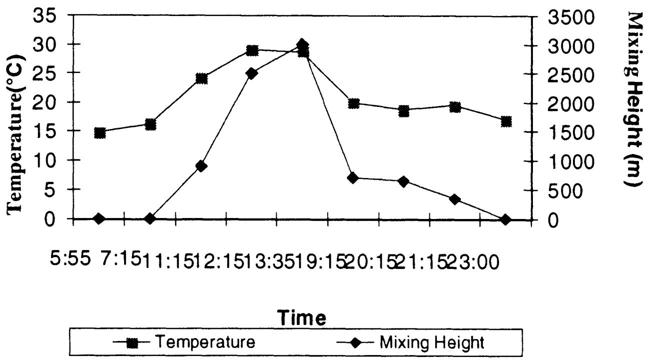

Fig 5. Diurnal Variation of Surface Temperature and Mixing Height at Shimla for Summer Season

2.3 Comparison between the two techniques

2.3.1. Inadequacies in radiosonde technique

There are several difficulties in using radiosonde data for air pollution modelling purposes. This is because the first reading regarding any parameter(which is measured by the radiosonde unit : temperature, pressure and humidity) is obtained at the first calibration point of the baroswitch which usually exceeds 300 meters. The important point here is the loss of vital and relevant information about the Planetary Boundary Layer(PBL) below this height, although we can still obtain mixing height data. The vital information refers to onset, decay, and the extent of fumigation in the morning hours after sunrise.

Radiosonde data primarily caters to upper air information relevant for aviation, weather forecasting purposes, and agricultural purposes(prediction of rainfall). Apart from this, the use of radiosonde data from meteorological station for other sites causes problems like :

- Radiosonde data from a regional meteorological station can be used after due extrapolations for smooth terrain only, for location within 200 kms of the station.
- In case the site is not close enough to the station the site specific mixing height should be adopted.

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- In coastal regions where the internal boundary layer penetration varies widely from 3 to 15 kms, site specific mixing height is required.

2.3.2. Advantages and disadvantages of minisonde technique

As compared to radiosonde, minisonde offers greater advantages, as follows :

- It provides higher temperature resolution due to slower ascent rate as compared to radiosonde, which has fast ascending balloon. Hence data pertaining to the lower few hundred meters is not lost.
- It is portable and offers both AC/DC modes of operation. It does not require specialized set up for operations and can be single handedly operated.
- Site specific mixing height and vertical wind profile can be obtained and used for air pollution dispersion modelling where such data is required.

However, there are some disadvantages which cannot be overlooked:

- Since it is not a usual operation by meteorological department, but rather by individual efforts, it is not possible to easily access such data, generated.
- Moreover it is not possible to generate data for such a vast country like ours, due to both financial and logistic constraints.

3 Air pollution potential index

High pollution potential is defined as a meteorological condition which, given the existence of emissions, would be conducive to the occurrence of poor air quality. This is stated in meteorological terms only and conditions are deliberately restrictive.

The Ventilation coefficient can be categorized into the following pollution potential zones:

<6000 m^2/s	High Pollution potential
6000-12000 m^2/s	Medium
>12000 m^2/s	Low

According to Gross 1970, the criteria for forecasting high pollution potential are that morning mixing depth should be less than or equal to 500 meters and transport wind speed lees than or equal to 4 m/s. The afternoon ventilation coefficient should be less than or equal to 6000 m^2/s and winds at height of 1500 m must average less than 10 m/s.

Aggarwal, 1991, [6]suggested 9 categories of air pollution potential based on Ventilation Coefficient. Categories 1,2,3 are indicative of high pollution potential and leads to wide spread occurrence of high concentration of pollutants. Categories 4,5,6 are medium pollution potential categories. Categories 7,8 & 9 are low pollution potential categories, which leads to high dilution of pollutants. The criteria for forecasting high pollution potential are hat the early morning or late night mixing depth (especially during winter season) are less than 500 meters and transport wind speeds corresponding to different directions is< 4m/s. Afternoon ventilation coefficient <= 6000 m2/s and wind speed <= 4 m/s. Such a criteria is widely used by U.S. National Weather Service (Gross 1970) and Atmospheric Environment Service Canada.

Table 2 gives the Air Pollution Potential Index(API) for different sites. It shows that sites near the coast like Patalganga and Vishakhapatnam have a very high value of Air Pollution Potential Index. Hence it can be said that

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coastal regions tend to allow accumulation of pollutants and hence are not favourable locations for polluting industries. However it is a well known fact that coastal regions are the most favoured regions for industrial growth. Inland regions like Satna have lower value even in winter season indicating lower air pollution potential. In our country due to high incoming soalr radiation inland regions like Satna have favourable meteorological conditions which allow quick dispersion of pollutants. Differences in insolation during summer and winter affect the dispersion capabilities. This can be seen by from Jagdishpur data. Summer is favourable season which can be seen by higher API and winter is highly unfavourable for dispersion. For hilly regions and valley meteorological conditions differ from site to site and depend on the topography that may accentuate or attenuate flow patterns. Hence, one can predict dispersion potential of various sites with similar topographical features in the country. However long term data from several sites all over the country will be required for such an analysis so as to build up a data bank of diffusion climatology in India which will be useful to regulatory bodies.

Table 2:Air pollution potential index for different sites in India

Site	Season	Max. Mixing Depth (m)	Max. Surface Temp (°C)	Mean Wind (m/s)	Ventila-tion Coeffi-cient (m^2/s)	Air Pollution Potential Index
INLAND						
Jagdishpur	**W**	**1920 m**	**28.7 °C**	**0.92**	**1766.4**	**1**
Jagdishpur	**S**	**3500 m**	**40.5 °C**	**3.06**	**9060**	**5**
Panipat	**W**	**1700 m**	**20.1 °C**	**1.05**	**1785**	**1**
Meerut	**W**	**1800 m**	**25.9 °C**	**3.18**	**5724**	**3**
Satna	**W**	**2850 m**	**39.9 °C**	**5.02**	**14307**	**8**
Surat	**S**	**2376 m**	**37.2 °C**	**2.79**	**6230**	**5**
Bardoli	**S**	**1530 m**	**39.5 °C**	**4.51**	**6900**	**5**
HILLY						
Yamuna Nagar	**S**	**1314 m**	**44.8 °C**	**3.79**	**4980**	**3**
Shimla	**S**	**3200 m**	**29.7 °C**	**2.12**	**6784**	**4**
Dharlaghat	**S**	**4000 m**	**27.4 °C**	**3.81**	**15240**	**8**
Hissar	**S**	**3000 m**	**39.9 °C**	**3.96**	**11880**	**6**
COASTAL						
Vizag	**S**	**828 m**	**38.9 °C**	**2.01**	**1664**	**1**
Patalganga	**W**	**2000 m**	**31.6 °C**	**0.99**	**1998**	**1**

W = Winter **S = Summer**

4 Conclusions

Mixing Height is a highly site specific parameter which depends on the topography of the region. It undergoes diurnal variation due to heating and cooling of the earth's surface. Trend analysis of long term mixing height data reveals that maximum mixing height undergoes an approximate sinusoidal variation over the year i.e. maximum mixing height reaches a peak value during summer and minimum during winter

The study shows that minisonde slow ascent balloon flights provide high resolution temperature lapse rate data as compared to radiosonde fast ascent balloon flights. Hence minisonde data is more reliable for determination of air pollution dispersion point of view where we are basically interested in the lower few meters above the surface of the earth. Moreover minisonde is useful for site specific data collection whereas radiosonde data extrapolation might be erroneous.

Generally inland sites have meteorological conditions which favor dispersion of pollutants. Inland sites have maximum dispersion capability hence low air pollution potential indices during summer and minimum hence high air pollution potential duirng winter. Coastal sites show that dispersion capability is generally low, with maximum in winter and minimum in summer.

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