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PREDICTION AND DETECTION OF ANTHROPOGENIC CLIMATE CHANGE : CASE OF DELHI

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ABSTRACT : The most apparent impact of anthropogenic stress on city local climate is the modification of the atmosphere environment by land use activities. The rapid growth of urbanization and industrialization inevitablly leads to higher consumption of energy usually reflected in increasing pollutant emissions. The paper analyses anthropogenic climate change detection taking empirical case study of Delhi Metropolitan City. Delhi is also known as Land locked city. Traffic congestion is a product of the rapid increase in the number of road vehicles. The trend in pollution emissions like CO_2 from all sectors shows upward trend due to rapid growth of urbanization in association with vehicularization and industrial emissions have been considerably increasing over a period. A major source of SO_2 emission in Delhi Metropolitan city is the industrial sector and thermal power plants. National Environmental Engineering Research Institute (NEERI) has estimated that these thermal power stations produce about 25550 tonnes of SO_2 per year. Total SO_2emissions are estimated at 45000 tonnes in 2000. Like emissions, the dominant sources of emissions are industry and thermal power plants. In 1990, total emission was about 115700 tones per year and will increase to 122600 tonnes per year by 2000. More than 90 per cent of industrial emissions are from thermal power stations. The levels of air pollution which is discharged from various sources concentrate in a particular area depends largely on local meteorological conditions, existing regulations and urban geometry. The impact of Delhi on its local climate are likely to change in climate parameters, however varies with each climatic variables. These annual pattern indicate that with maximum and minimum temperature for Delhi have positive anomalies. Inadvertent modification with respect to temperature, relative humidity and surface wind were evident not only when data within the core area of city were comp[ared with city's fringe area. Surface wind speeds are found high in the core area of the city at times of light winds, with strong winds however there is a decrease. Temperature is higher and relative humidity is lower in the core city area as compare to its fringe area. The precipitation ratio shows the intensity of precipitation tends to increasing trend.

INTRODUCTION

A large and increasing proportion of the population of India lives in metropolitan cities. Thus the exposure of air pollution occurs to people in urban areas. In spite of improved pollution-control technology, the continued growth of cities and especially of vehicular traffic suggest that there will be no decrease in this exposure in the short run. To make rational choices between various land-use and pollution-control strategies, decision makers require information about how the distribution of emissions and meteorological factors combine to affect urban air pollution concentrations. Metropolitan cities usually have extremely high population densities, especially in central districts, which experience motor vehicular traffic congestion resulting in high concentration of air pollution emissions. The presence of built-up areas, which extend for tens of kilometres alter the normal wind circulation and the urban heat islands may exist due to high dissipation (Oke, 1973; Bahl et al.,1979). Urban agglomerations form a continuum of developed land without green belts or natural barriers. Air pollution levels can steadily increase as the air masses circulate over such areas (Singh and Kumar, 1993; 1996).

The present paper has three objectives. These are :

1. To understand the role of urban growth and anthropogenic forces in changing the metropolitan atmospheric quality.
2. To assess the geographical/locational factors responsible for heavy concentration of pollutants in city atmosphere.
3. To study the spatial variations of atmospheric conditions within a metropolitan city.

STUDY AREA

Geographically, Delhi (28°35'N latitude,77°12'E longitude), lies 216m above mean sea level and is situated in the National Capital Territory (NCT) in the North of India, 160 Km south of the Himalayas. Delhi is also known as a land locked city. Delhi with 8.42 million population is the third largest city of India. As the capital city it has become a nucleus of trade, commerce and industry in the nrothern region of India. Major industrial activities exist in the west, south and south east zones of the city. Engineering, clothing and chemicals predominate, although electronics and electrical goods are main industries of the city. The city is categorised as a service town, alongside which industries are rapidly expanding (Table 1). The Delhi Ridge has been converted into parks. Though this may not seem important to most joggers and strollers, such activity has wreaked havoc upon the scrub vegetation of the Ridge. Parks are certainly essential in a city like Delhi, but they can easily be planned in other areas (already denuded of forests), without tampering with the Ridge.

Traffic congestion in India in general and in Delhi in particular is a product of the rapid increase in the number of vehicles on the roads. Congestion is most pronounced in the old Delhi city areas, which have narrow streets and inadequate parking facilities. The expansion of Old Delhi and New Delhi has been accompanied by a marked growth in the number of people commuting to and from Delhi. Commuters are forced to depend on road transport and traffic densities have increased, particularly along the highways and internal roads of the city.

Table 1

Growth of Industries in Delhi

Year	1951	1961	1965	1978	1981	1985	1990	1991	1993
Number of Industries	8,000	17,000	19,308	40,000	46,000	65,000	81,000	85,000	93,000

Source : Bureau of Economics and Statistics Hand Book of Delhi, Delhi Administration.

METROPOLITANIZATION IN INDIA

In post-Independence period, India has observed a new pattern of urban growth known as metropolitanization. A remarkable feature of the urbanization is the rapid rise of number of metropolitan cities. The number of metropolitan cities grew from 1 in 1901 to 23 in 1991. The number of metropolitan cities became 2 in 1911 and till 1941, there were only two metropolitan cities. During the decade (1981-91), the number if such cities increased from 12 to 23. These 23 cities in India account for 32.62 per cent of the total urban population. The number of metropolitan cities has almost doubled. The 1981-91 decade can be named as "the decade of metropolitanization" (Table-2).

Percentage of urban population living in metropolitan cities was 5.84 per cent in 1901, 10.68 per cent in 1911, 11.11 per cent in 1921, 10.19 per cent in 1931, 12.03 per cent in 1941, 18.80 per cent in 1951, 22.93 per cent in 1961, 25.52 per cent in 1971, 26.42 per cent in 1981 respectively. As per census report 1991, 32.62

Table 2

Trend of Metropolitanization in India (Population in million)

Name of Cities	1901	1911	1921	1931	1941	1951	1961	1971	1981	1991
Mumbai	-	1.02	1.24	1.27	1:69	2.97	4.15	5.97	8.24	12.60
Calcutta	1.51	1.75	1.88	2.14	3.62	4.67	5.98	7.42	9.19	11.02
Delhi						1.44	2.36	3.65	5.73	8.42
Chennai						1.53	1.94	3.17	4.29	5.24
Hydarabad						1.13	1.25	1.80	2.55	4.34
Banglore							1.21	1.66	2.29	4.13
Ahmadabad							1.21	1.75	2.55	3.31
Pune								1.14	1.69	2.49
Kanpur								1.28	1.64	2.03
Lucknow									0.01	1.67
Nagpur									1.30	1.66
Surat									-	1.52
Jaipur									1.02	1.52
Kochi										1.14
Vadodara										1.13
Indore										1.11
Coimbatore										1.10
Patna										1.10
Madurai										1.09
Bhopal										1.06
Visakhpatanam										1.06
Ludhiana										1.04
Varanasi										1.03
Total No. of Metros.	**1**	**2**	**2**	**?**	**2**	**5**	**7**	**9**	**12**	**23**

Source : Census of India.

per cent urban population resided in these cities as indicated above. The Census of 1981 classification has introduced for the first time the term mega-cities, which is defined as the cities with a population more than five million. In 1991 there were four mega cities(Mumbai, Calcutta, Chennai and Delhi) in India. Likewise, out of the total 77.99 million population in the metropolitan cities, 37.46 million are in the four mega-cities constituting 52.78 per cent of the total metropolitan cities population.

URBAN EXPANSION

Delhi Metropolitan city lies on both sides of the river Yamuna. Earlier, Delhi was situated on western bank of the River Yamuna. The city and the area surrounding it are believed to have been the site of many ancient and medieval cities. The present old city was built in medieval period. From 1921 to 1931, Delhi was the capital of British India, when a new city called New Delhi was established at a distance of five kilometres. The present Delhi has joined old the capitals as successive cities in descending order viz -Indraprastha, Tughlakabad, Lalkot, Jahanpanah, Siri, Purana Qila, Shahjahanabad, Firozabad, New Delhi, and are coalesced together. These settlements even jointly did not contribute to grow to a size of a metropolis upto 1941, when population was 6.96 lakhs. After the partition of India, it is estimated that about 1 lakh people left for Pakistan but thrice that number came to Delhi which doubled its population. The growth of population has been observed to be 106.6 per cent during 1941-51 decade. It is the highest ever growth an urban settlement in India had experienced. Thus, the Metropolitan transformation processes have been taking place from 1947 onwards.

The area of Delhi Metropolitan city has been continuously increasing since 1961 experiencing 36.66 per cent (1961-71), 21.18 per cent (1971-81), and 15.44 per cent (1981-91) growth. Delhi Metropolitan City has already engulfed vast tracts of the surrounding land by a dramatic sprawl. Spreading in all directions from the twin centres of old and New Delhi, the post-Independence city has accelerated its suburban expansion with government built and privately owned flats and houses. Together they have produced a third city that has already dwarfed the earlier two centres (Fig.1)

AIR POLLUTION VARIATION AND URBAN LAND USE PATTERN

Air pollution is the most common problem in a city area where large concentration of various anthropogenic activities cause significant amount of pollutants being emitted into the atmosphere. The major pollutants are SO_2, NO_2, SPM, CO and hydrocarbons. These pollutants are present in densely populated urban areas in significant concentrations becauses of increasing anthropogenic activities i.e. industrialization, dense population and high traffice density, and the closeness of industrial areas to residential districts. The nature and relevance of air pollution problems in urban areas differ depending upon climate, local meteorological conditions, existing regulations and urban geometry (Berry et al., 1974; Detwyler et al., 1980).

The annual mean concentration trend for SPM shows a gradual increase from 1978 to 1995, followed by slight fluctuations. The ambient concentrations in Delhi are persistenly above the Central Pollution Control Board (CPCB) guidelines. After 1987, Delhi became highly concentrated with SPM pollutants into the atmosphere. The annual mean concentration trend for SO_2 is clearly downward with high fluctuations. In Delhi, the annual mean concentration trend for NO_2 appears gradually

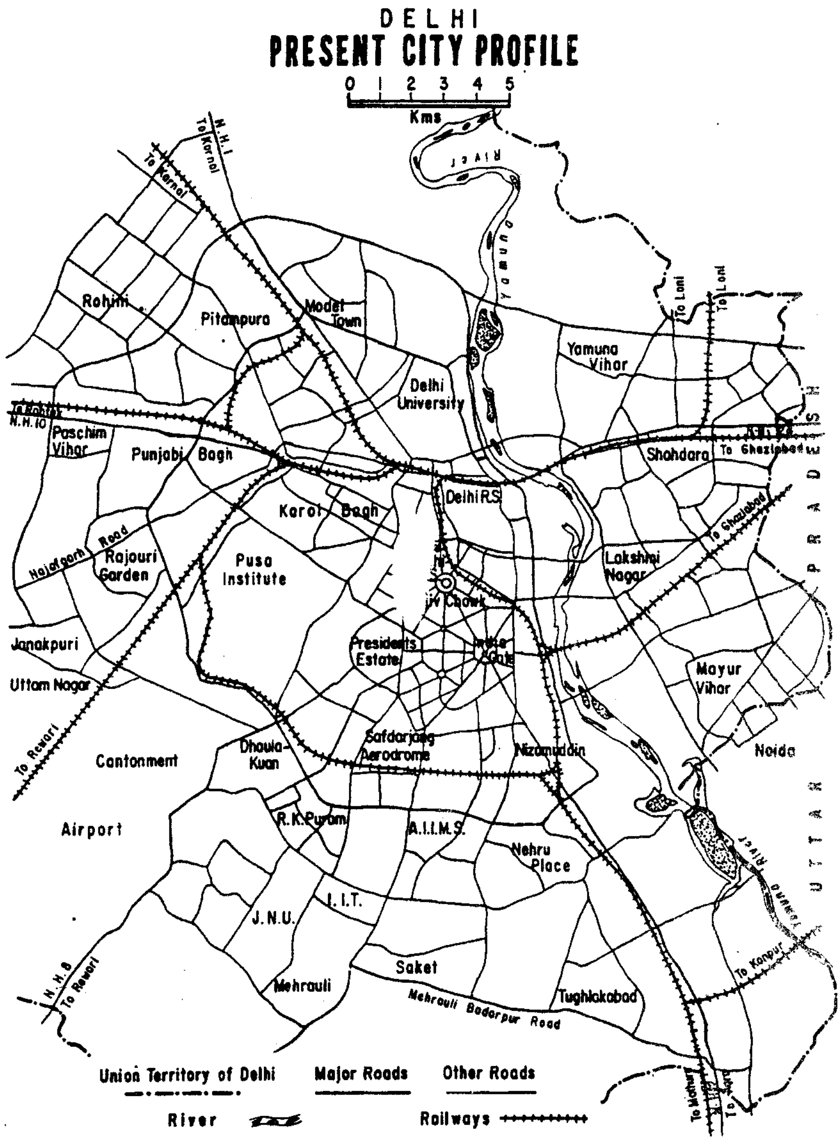

Fig. 1 : Delhi - Present city profile

increasing from 1978 to 1995. In Delhi, the annual mean concentration of NO_2 is least fluctuating. Delhi suffers equally from pollution caused by motor vehicles, which constitute about 50 per cent of the pollutants creating smog and 90 per cent monoxide concentration in the city's atmosphere. In addition, motor vehicles emit more than 250 tons of carbon monoxide, 40 tons of hydrocarbons and 30 tons of NO_2 etc. The situation becomes further complicated by huge quantities (over 1000 tons) of ash emitted from thermal power plants of Indraprastha and Badarpur. These may be marked out by greater degree of pollution in and around localities of Lawrence road, Wazirpur, Shahadara, Shahzadabagh etc., where a number of industrial units are emitting air pollutants like SO_2, SPM and other particulate in the air (Fig.2).

CLIMATIC SCENARIO

Urban growth usually involves structural changes and changes in local functions, all of which will affect the degree of urban warming. There will, of course, be very drastic changes, should an originally rural climatological station be engulfed by urban sprawl -But any subsequent expansion of the city beyond the station will usually have much less effect upon its records, provided there are no changes in character of immediate station environment (Chandler, 1964).

The overall climate of a city reflects the region where the city is located. But large cities can modify some of the climatological factors in their immediate vicinity, resulting in a relatively small-scale but important variation in climate, which is called a microclimate. The study based on Delhi however, indicates that there is a two way relationship between meteorological processes and atmospheric pollution. The main objective in this study is to identify air pollution and growth of urbanization and its impact on climatic parameters, considered together.

Delhi has tropical steppe climate with extremely hot summers and moderately cold winters. Only during the monsoon period (July to September) does air of oceanic origin pernetrate in to Delhi and causes increased humidity, cloudiness and precipitation. The weather conditions of Delhi are influenced by the inland position with the great desert of Rajasthan to west and south-west and Gangetic plain of Uttar Pradesh to the east. Extreme dryness with intensely hot summers and cold winters are the characteristic feature of the weather. The cold season starts in late November and extends to about the beginning of March. This is followed by the hot season, which lasts till about the end of June when the monsoon arrives. The total mean annual rainfall is 715-mm. Maximum rainfall occurs in July (211 mm). The monsoon continues up to the last week of September. The post monsoon (October and November) constitutes a transition period from the monsoon to winter conditions.

WIND SPEED AND DIRECTION

The city area tends to modify the airflow with weak wind and it may generate its own circulation system. City air circulation system is formed with convergence of flows in density, and a consequent vertical motion of the now specifically lighter air above the area in pressure at ground level and consequently to the lateral movement of air towards the area of minimum pressure.

In Delhi Metropolitan City and its fringe showed that the winds are either calm or light in the suburbs but accelerated towards warm pocket/heat island region to 10 kilometre per hour (kmph). Secondly, the wind speeds being low showed an anticyclone curvature particular on 23-24 March, 1978. Similar to extratropical urban climatic sutdies reported earlier. With the meagre data it was not possible to delineate a critical wind speed or strength of inversion at which acceleration of wind occurs (Padmanabhamurty et al., 1981).

In Delhi, during the winter and post monsoon period winds are usually clam/light. But in the winter months city has experienced the most

Spatial Distribution of Air Pollution in Delhi

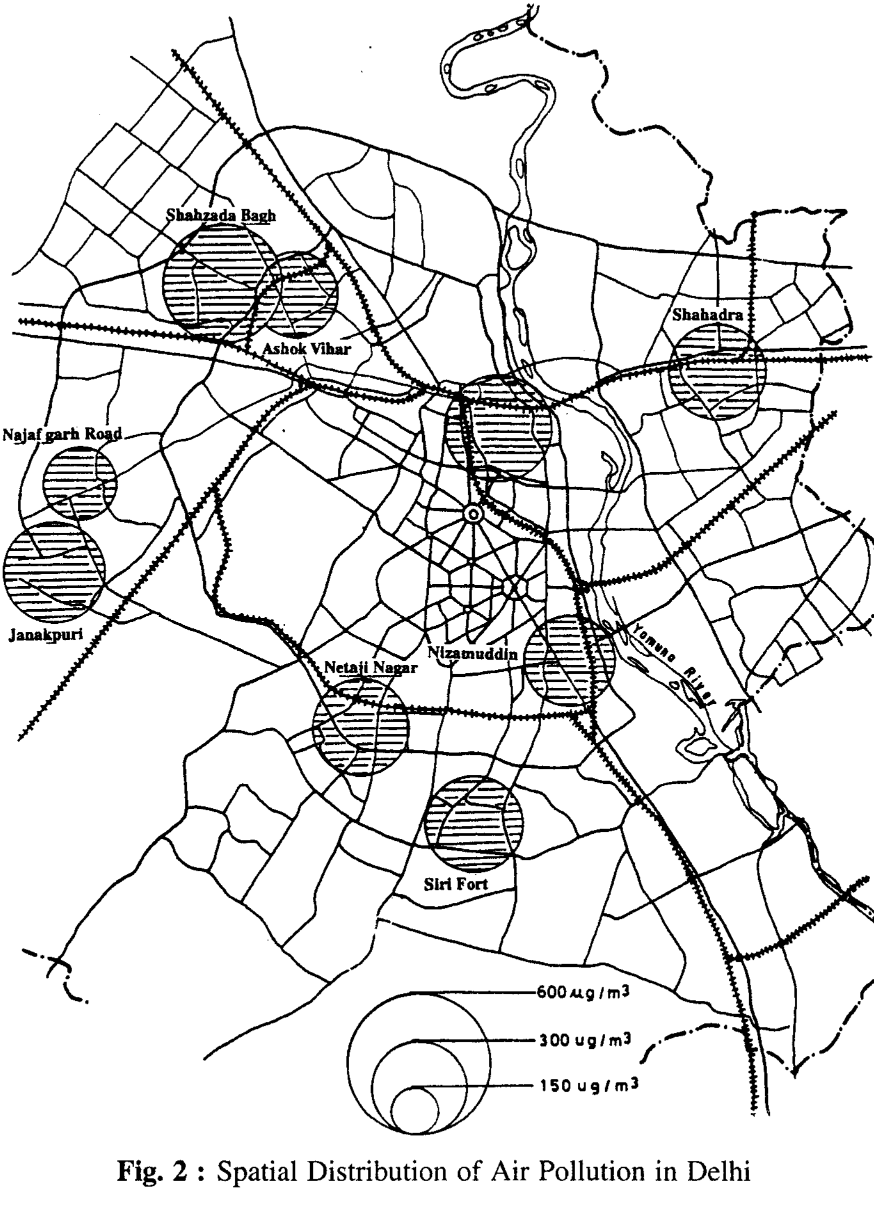

Fig. 2 : Spatial Distribution of Air Pollution in Delhi

predominant direction of surface wind is W to NW with speed 7-15 kmph. In the wake of western disturbance in winter season, temperatures become low with cold waves. Wind speeds are higher during the premonsoon (summer) and monsoon period. The winds during the pre monsoon (April to June) period have dominance of NW-W direction though the winds from other directions also occurred frequently. On the other hand, during the monsoon period Easterly and south easterly winds are more dominant.

April to June is the period with the highest incidence of thunderstorms and dust storms. Some thunderstorms give rise to viloent squalls (Andhis). While some of the thunderstorms are dry, others are accompanied with heavy rains and less frequently with hail. Thunderstorms also occur in the winter months in association with westerly disturbances and sometimes-dense fog occurs during this time.

AIR FLOW CHARACTERISTIC

In the present study to show the wind condition at the surface, wind rose diagrams have been constructed with data of one surface station (Safdarjung) for the 1980-1985 (Fig.3). During the summers of 1980-85, it showed the winds prevailing from NW-W direction. This dominance of winds gradually decreased and winds form other directions also occurred frequently. In the same period (1980-85), it was observed that SE winds picked up. The total mean annual scene of wind roses represent that throughout the year about 38 per cent of time NW winds occurred. From an analysis of mean wind speed and direction at Safdarjung Meteorological Station, it is observed to be particularly evident during the summer and monsoon months when mean wind speeds are relatively stronger. When NW winds are blowing then core of the Delhi Metropolitan City area falls in the downwind direction of the large industrial areas. This reversal of the city influence lies chiefly in the diurnal cycle of wind speeds and stability. When wind speeds are low, pollutants tend to be concentrated near the area of discharge and the longer the periods of such light winds, the greater will be the concentration of pollutants. Further, gushiness, a very important characteristic of surface winds is directly proportional to its speed and determines the extent to which the pollutants are mixed and diluted with the surrounding air.

In city areas, the temperature within the city is generally higher than in its fringe areas. Within an urban complex, temperature of the entire city area is not equal. City temperatures vary in accordance with its land use activities. The micro-climatic variations that have been found in large cities due to increase in growth and thee dimensional complexity. In Delhi, the cold season starts towards the latter half of November when both day and night temperatures drop rapidly with the advance of the season. January is the coldest month with the mean daily maximum temperature at 21.3°C and the average daily minimum at 7.3°C. In the winter months cold waves affect Delhi in the wake of western disturbances passing across northern India. The long-term temperature variation (1901-92) has shown negative trend. Mobile temperature surveys were conducted in Delhi during the winter months in the early hours of 18 December 1976, the temperature differences between city area and it fringe area was 5°C during December, which increased to nearly 7°C in the months of January to March.The formation of heat island within the thickly populated walled city encompassing areas from Delhi Gate, Chandni Chowk to Ajmeri Gate. Secondly, "heat islands" in the trans Yamuna area and near Yasuf Sarai area in South Delhi are also found. The exact shape and location of the 'heat island' varied slightly from month to month in cold weather period depending upon prevailing winds, local influences and terairn conditions.The analysis of temperature at these two stations (Safdarjung at city area and Palam at South West city fringe area) during 1980-94, shows annual pattern of change in the intensity of Delhi heat island. The number of occurrence of temperature differences is represented as percentage for each month. These annual patterns indicate that maximum and minimum temperature for

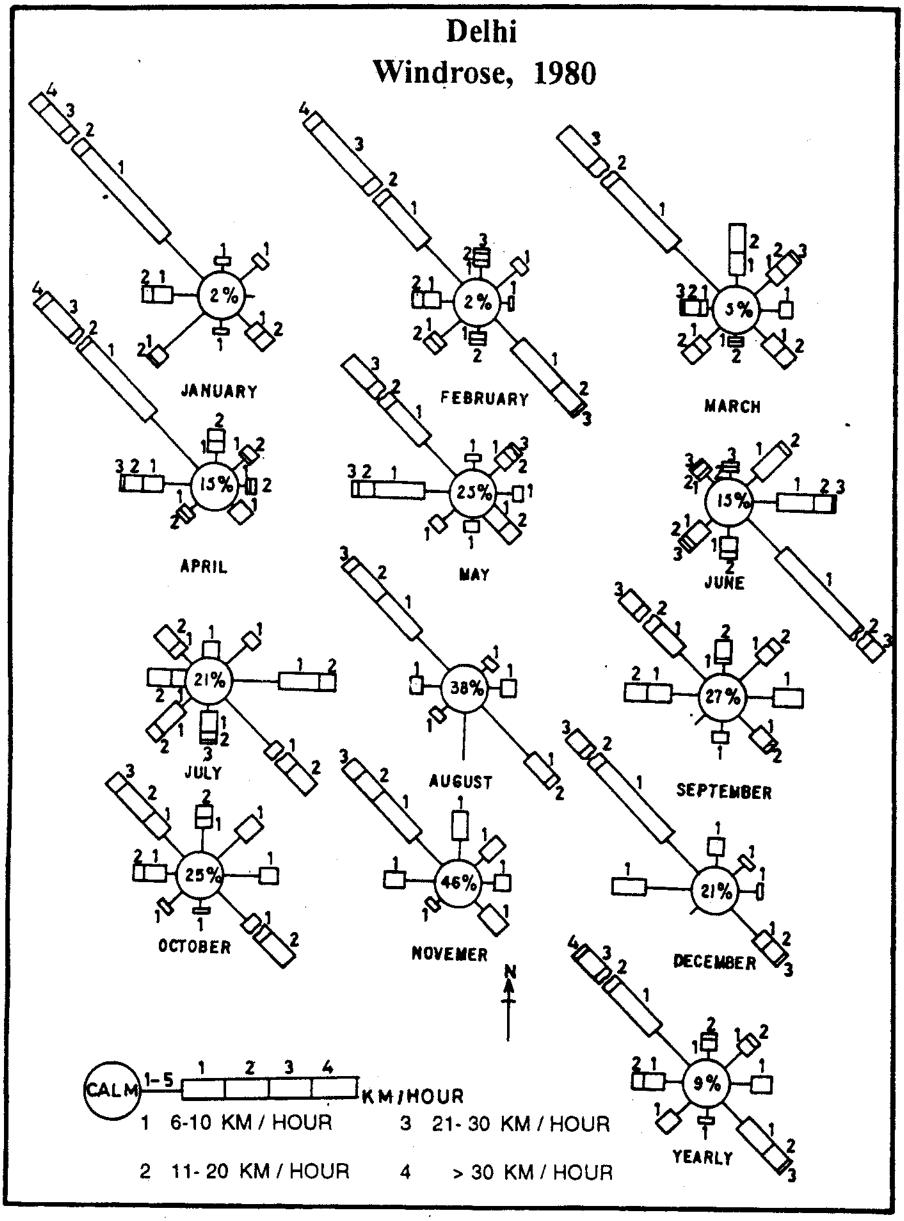

Fig. 3 a : Delhi - Windrose, 1980

Delhi have positive anomalies. The difference in maximum temperature, shows maximum from March to November and January, February and December months are minimum in values. The patterns from difference in daily maximum and minimum temperature have shown Safdarjung warmer than Palam. Safdarjung is situated very close to the core of Delhi Metropolitan City i.e. Rajiv Chowk (Connaught Place) in central and Yusuf Sarai in South. These core areas of Delhi metropolitan city exhibit warm pockets due to

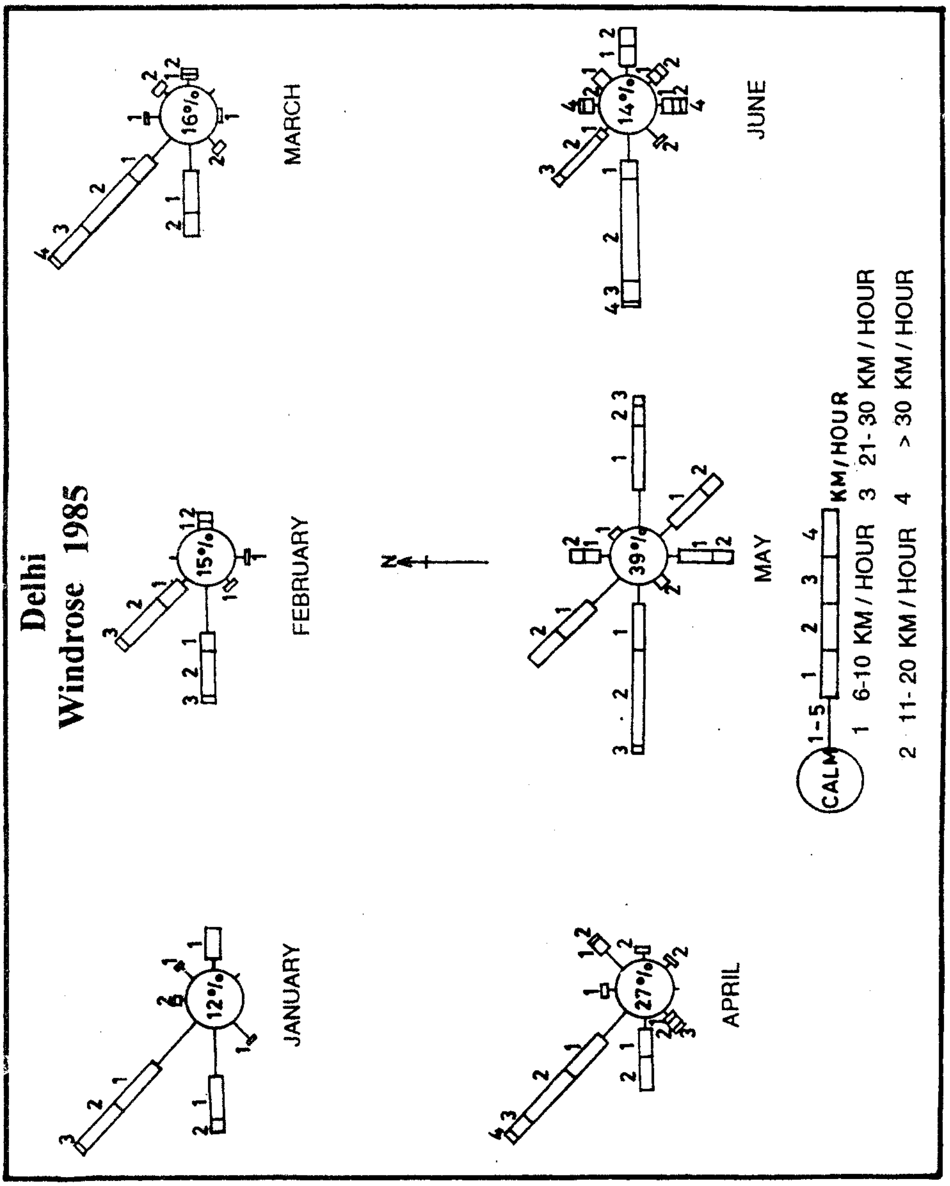

Fig. 3 b : Delhi - Windrose, 1985

the thermal radiation emissions. The thermal radiant emittance from different surfaces in Delhi are responsible for the formation of several warm pockets instead of a single intense 'heat island' (Padmanabhamurty et al., 1982). There is no clear identification and explanation for intense "heat island" because of meagre data. It is very difficult to delineate several warm pockets.

RELATIVE HUMIDITY ANALYSIS

The pattern of relative humidity differences within Delhi metropolitan city core area at Safdarjung and city's fringe at Palam is

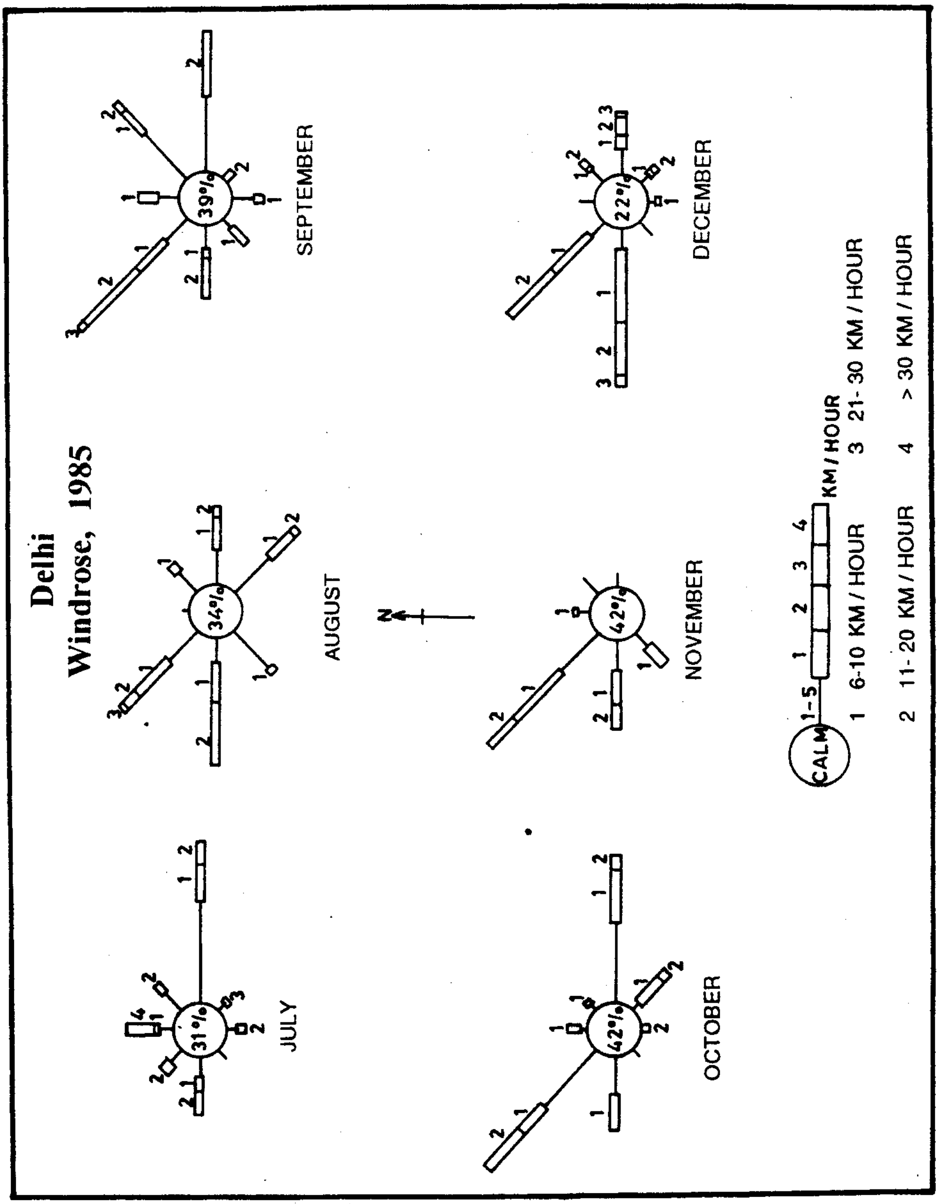

Fig. 3 c : Delhi - Windrose, 1985

provided. The Table shows the average maximum and minimum monthly data for the two stations during 1980-9\85 respectively. The mean relative humidity around Safdarjung is lower than the Palam. The average maximum and minimum monthly relative humidity at Safdarjung tend to be lower in comparison to Palam, most of the month. Differences of relative humidity for Sardarjung show that most of the months have positive anomalies, and also show that Summer seasons have less relative humidity due to stronger wind speed.

It is generally observed that wind speeds are low when urban-rural heat/humidity differences are large, suggesting an inverse realtionship. When wind speeds are strong it is also observed that urban-rural heat and humidy fields are displaced downwind (Padmanabhamurty, 1986).

The study shows the details of the precipitation at thirteen stations from 1901 to 1985 for Delhi Metropolitan Cities. The normal annual precipitation in Delhi is 611.8 mm. The observed precipitation is received as winter rain (due to western disturbance) and as thunderstorm rain in the pre and post monsoon periods. During the 85 year period 1901-1985, Delhi received highest annual precipitation which amounted to 251 per cent of the normal in 1933. In 1951, the year with the lowest rainfall only 44 per cent of the annual average precipitation was received. It was observed that during 1901-85 period precipitation was less than 80 per cent of the normal in 21 years. This also shows that in 61 years out of 78 years, the precipitation range was 401-1000mm. On the other hand 6 years come under 1001-1600 precipitation range (Fig. 4 & 5).

The pattern of annual precipitation ratios for the 1965-85 period and for the decade 1975-85 are showing, North, East and Central part of the Delhi metrooilitan city which covered high intensity of precipitation ratio. Western part of the Delhi metropolitan has less intensity of precipitation ratio. The area of high intensity of precipitation ratio are the most disputed effect of anthropogenic activities. Out of thirteen stations Chandrawal station has received high precipitation ratio followed by Delhi University, Palam, Okhla, Safdarjung and Delhi Sadar respectively. Delhi Sadar and Okhla are thickly populated areas. Delhi Sadar is famous for commercial activities. On the other hand, Okhla has industrial activities concentrations. It is observed that there is conclusive evidence of intensification in precipitation with progressing time with respect to city's average precipitation. In other words, we may say that city precipitation ratio had found a low degree of radical change in the decade 1975-85 as comapred to long term average (1965-85). In the above study, it is felt that such type of precipitation variability and changes support the hypothesis of Changnon (1969, 1980) that urbanization tends to increase precipitation.

CONCLUDING REMARKS

Metropolitan cities atmosphere are not uniform. The poor air quality over cities often has major impact on surrounding regions. Metropolitan cities with major air quality problems occur in every continent except Antarctica. Indian metros have a very dense network of sources of functional potentiality with considerable variety. The complexities of Indian metros's physical structure create problems for measurement of representative pollution concentrations and spatial distributions of pollutants across the city landscape. However, measurements are crucial because cities are now, and are likely to be for some time the major source of anthropogenic emissions affecting global air quality. In Indian metros,the emerging environmental problems are mainly attirbuted to the greater concentration of population, major shift in location of the most populous cities, industrial activities and increasing number of vehicles associated with traffic problems virtually in all the selected Inidan Metros (Mumbai, Calcutta and Delhi).

The above noted objectives have been approached through secondary sources of data, collected from various Government

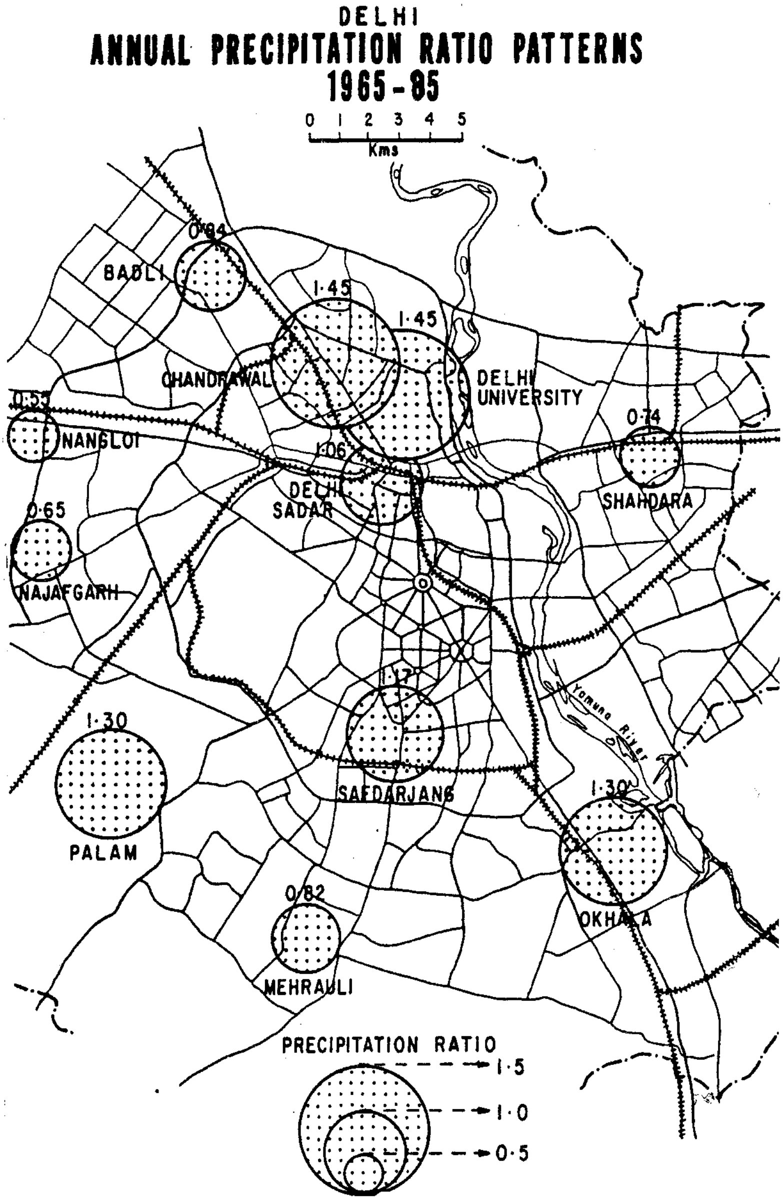

Fig. 4 : Delhi - Annual Precipitation ratio patterns - 1965-85

Institutions/Laboratories. An attempt has been made to establish the correlation between the pace of urbanization and the city's physical expansion of Indian metros. By examining this an assessment has been made of the implications of climate for air pollution potential. The concentration of pollution levels for major pollutants and climatic tempreature affecting them have been considered.

The main observations that were observed from the paper may be concluded as follows:

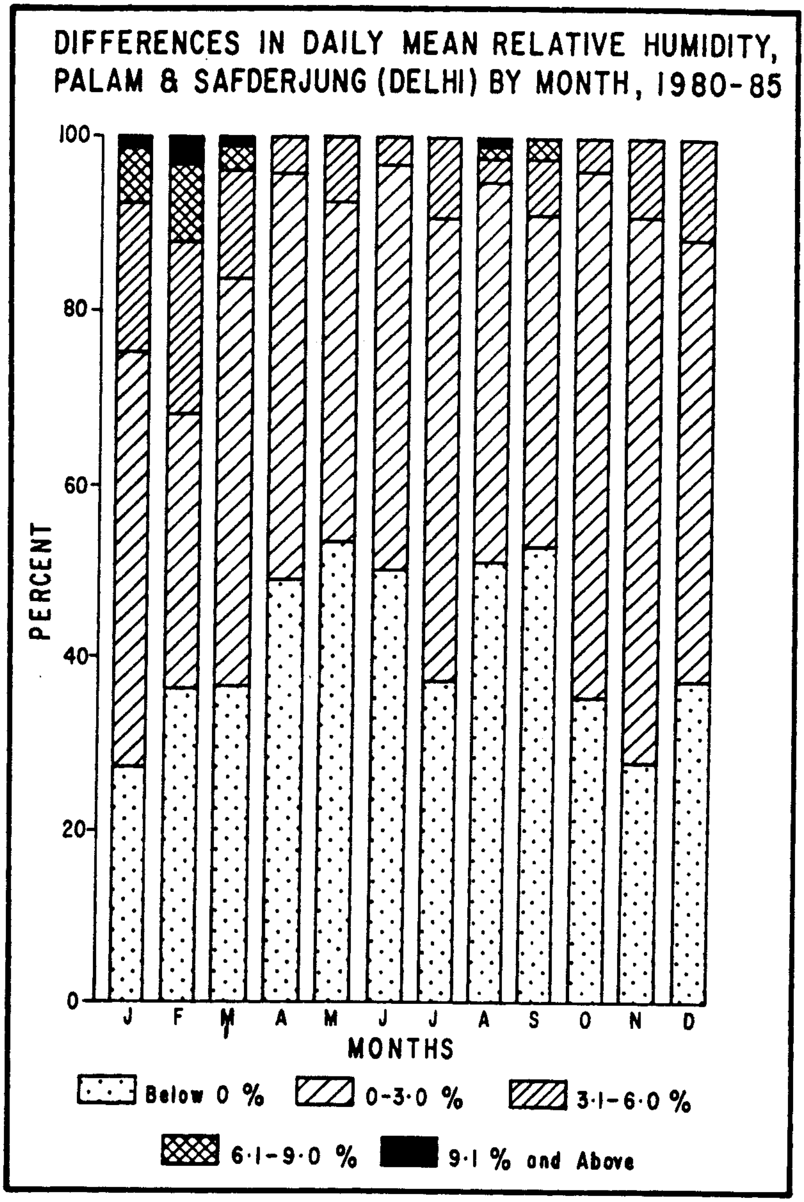

Fig. 5 : Differences in daily mean relative humidity, palam & Safderjung by month, 1980-85

FINDINGS AND CONCLUSIONS

The urban sprawl is not based on a certain ceriteria. It has been spreading spontaneously in an unplanned manner. The trend in pollution emissions from all sectors in the city shows upward trend due to rapid growth of urbanisation in association with vehicularisation and industrialisation. Air pollution is widespread in the city where all major pollutants exceed the Central Pollution Control Board (CPCB) guidelines. Long-term variation of surface temperature differs from each other. Delhi has shown significant cooling trend which is observed in the maximum temperature differences. Local climate affects the specific location of the station in relation to the city centre, and the spatial attributes may make results considerably different. City impact on its local climate is likely to change its climatic parameters which however, varies with each climatic variable. Inadvertent modification with respect to temperature, relative humidity and surface wind were evident when data within the core area of city were compared with city's fringe area. Surface wind speeds are found high in the core area of the city during the time of light winds. Despite Delhi's urban geometry and wind direction, the city's core area shows wind direction which tends to frequently change in accordance to urban geometry. Temperature is higher and relative humidity is lower in the core city area as compared to its fringe area. The precipitation ratio shows the intensity of precipitation towards an increasing trend.

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