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Ecoclimatic modification of Delhi due to urbanization

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ABSTRACT. Temperature, humidity and wind fields at the surface over Delhi during winter period are presented. The temperature analysis suggests several warm pockets and cold pools. The humidity field indicates an inverse relation with temperature except close to water surfaces or green vegetation. Wind fields tend to be anticyclonic. Climograms for urban and rural Delhi point out the differences in comfort at both the localities. During day time rural Delhi is comfortable in February, March and December but at urban Delhi January, February and December are comfortable. Similarly, during night time while rural Delhi is comfortable in May and June only, urban Delhi is comfortable in April, October and November. Remaining months in each case are uncomfortable either on the hotter side or colder side.

1. Introduction

Ecoclimate, more comprehensively called habitat climate, deals with the study of the climate near the ground. Ecoclimate of an urban area, otherwise known as urban climate is of more than academic interest because of its practical importance in the proper design of buildings and cities to secure maximum comfort as well as optimum socio-economic performance and in pollution dispersion studies.

Heat capacities, conductivities, heat storage and thermal lag in the urban thermal system as compared with that in rural areas are often quoted as fundamental to the genesis of heat islands (Clarke and Peterson 1972; Oke and Fuggle 1972). These factors are of varying importance in different geographic locations. A detailed study of the temperature field over cities and rural environs is necessary for a better understanding of the imbalances in their dispersive capacities of atmospheric pollutants.

Studies made in cities have shown that average wind speeds are generally lower in built-up areas than over rural areas (Munn 1970) but Bornstein *et al.* (1972) have shown that difference in wind strength between town and country is a function of the regional near surface wind speed and wind profile. As regards wind direction within the city it is very closely controlled by the form of the buildings and the patterns of streets and open spaces, as well as, by the topography upon which the city is built. Knowledge of the distribution of wind speed and direction is a prerequisite for the study of transport and diffusion of pollutants, as well as for human comfort.

Contrasts in evaporation rates between urban and rural environs manifest themselves in differences in absolute humidity when the atmosphere is calm. Patterns of humidities in cities are closely related to the detailed form of their heat islands which in turn depend upon the distribution of urban building densities [Chandler 1967(b)]. Humidity islands play a key role in determining the residence times of pollutants, their rate of deposition and chemical action on the exposed objects.

It is often reported in literature that the vast majority of ecoclimatic studies have been made in mid-latitude cities and emphasis also was laid for similar studies in low latitude cities (WMO 1970). In the present paper, therefore, some ecoclimatic aspects of Delhi in winter months are presented and discussed.

2. Methodology

The meteorological and topographical features

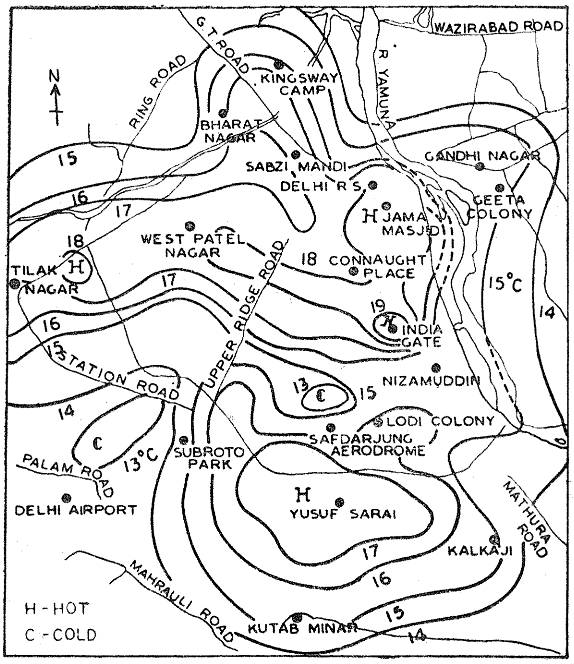

Fig. 1. Isothermal analysis at Delhi at minimum temperature epoch 23-24 March 1978

of Delhi were described in an earlier paper (Bahl and Padmanabhamurty 1979). Temperature, humidity, wind speed and direction were obtained at each observation point in the survey from a number of fixed and mobile stations. Details of collection of data, instruments used and the method of reduction to minimum temperature epoch were described earlier by authors (Bahl and Padmanabhamurty 1979). The method of reduction to minimum temperature epoch remains the same in respect of temperature, relative humidity and dew point but wind speed and direction were not reduced due to their insignificant variation.

3. Results and discussion

Fig. 1 shows the pattern of isotherms at the minimum temperature epoch on the night of survey in March, 1978. The surface 'heat island' intensity at this period is most important as it provides the driving force for horizontal pollutant transport since vertical transport is inhibited by stable/inversion layers. The intensities of heat island alongwith prevailing weather conditions are tabulated (Table 1) below :

TABLE 1

Date (1978)	Heat island intensity (°C)	Wind speed and direction	Cloud
25/26 Feb	6.1	3-5 kmph/W to WNW	Clear sky
23/24 Mar	5.4	10-14 kmph/W-calm by morning	Partly cloudy with *Ci* developed to 7/8 low and medium as *As* by morning

3.1. *Temperature field*

The surveys pointed out that 'heat island' is seen to be invariably within the thickly populated walled city extending from Delhi Gate, Chandni

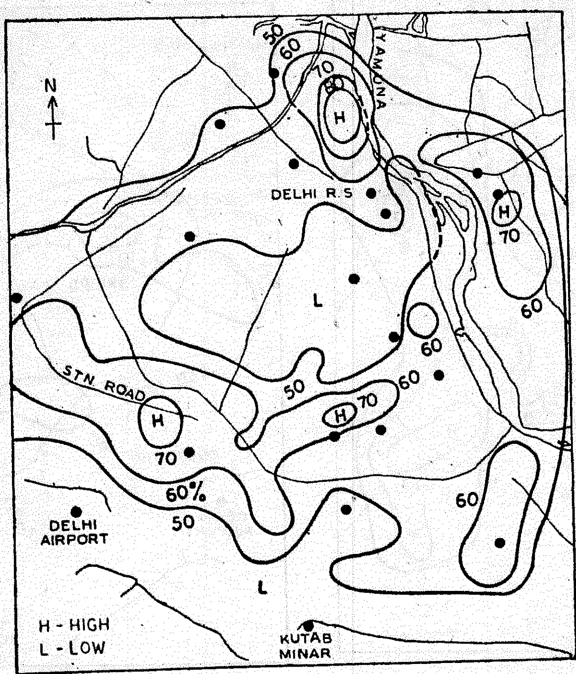

Fig. 2. Isohumes at Delhi at minimum temperature epoch 23-24 March 1978

Chowk to Ajmeri Gate. The position of main 'heat island' in this area confirmed the earlier findings (Bahl and Padmanabhamurty 1979). Warm pockets have also been noticed in the trans-Jamuna area in the northeast and near Yusuf Sarai in the south. Close groups of buildings in the vast open areas appeared as warm pockets. The coldest area observed in these surveys was towards western Delhi Cantonment and Palam. The isothermal pattern indicates the penetration of the cold air from west to east upto river bed. The difference in temperature of the suburbs was about 5-6 deg. C. Increased low cloud and windy conditions reduced the heat island intensity. In contrast to these findings the heat island intensities in extratropical cities have been reported to be from 5-11 deg. C (Padmanabhamurty and Hirt 1974).

Topography and river *Yamuna* have their own share in modifying the urban climate of Delhi. Close network of observations in 1978 showed several warm pockets extending from Geeta Colony to Tilak Nagar through Hauz Khas, Pahari Dhiraj area and Sat Nagar which are closely skirting the *Yamuna* river flowing through eastern Delhi and the Najafgarh Nalla towards northwest Delhi. The existence of main heat island at Delhi Gate and a warm pocket at Geeta Colony in the west and east of *Yamuna* river seem to be influenced by the proximity to the river which tends to increase the surface humidity and consequent reduction in radiative cooling of the lower layers over this area.

3.2. *Humidity field*

Relative humidities, being a function of prevailing temperatures, are normally found to be inversely related in towns to the local intensity of the urban heat island. On an annual average urban/rural differences are reported to be 5 per cent but on individual nights these differences may approach 20-30 per cent [Chandler 1967 (a)].

Fig. 2 shows the pattern of relative humidities. As the humidity changes can be better appreciated by dew point distribution Fig. 3 is plotted for the purpose. Considering the main heat island and warm pockets located away from water bodies or evaporating surface the inverse relationship between relative humidity and temperature is noticed. Likewise the inverse relationship between warm pockets and dew point could only be observed in areas away from the water bodies. Warm pockets adjoining river *Yamuna* or Najafgarh nalla recorded high relative humidity because of availability of adequate moisture in proportion to the demand.

Urban/rural differences in relative humidity were as large as 30 per cent in February but is only 20 per cent in March. This suggests that

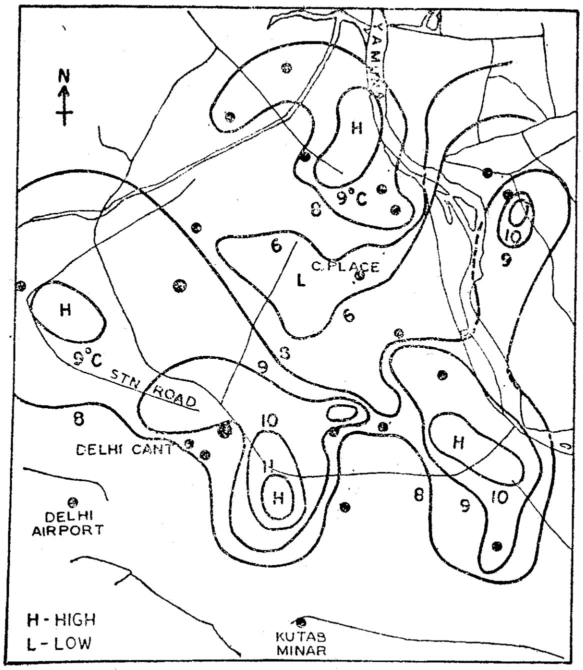

Fig. 3. Isolines of dew point at Delhi at minimum temperature epoch 23-24 March 1978

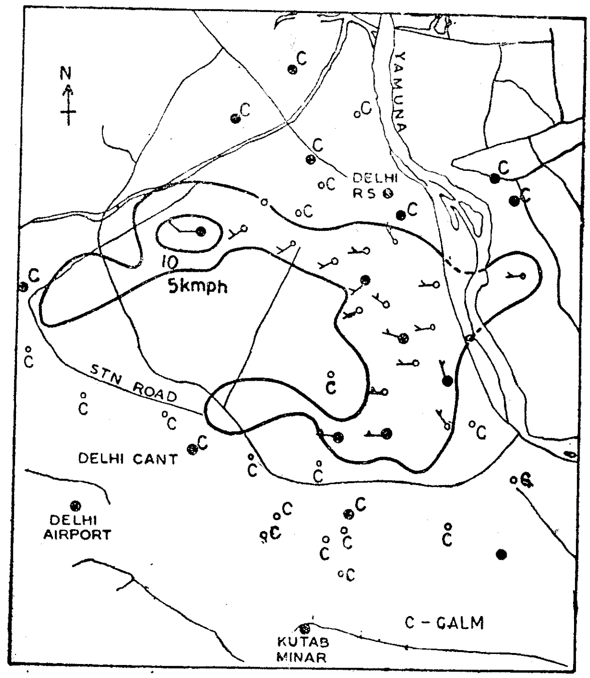

Fig. 4. Isotach analysis at Delhi 23-24 March 1978

there is not much difference in tropical and extratropical cities in this respect. Dew point difference is about 2 deg. C in either of the months.

3.3. *Wind field*

Bornstein *et al.* (1972) working on measurements in and around New York showed that when winds were light, near surface speeds were greater in the built-up area than outside, whereas the reverse relationship existed when winds were strong. The acceleration of speeds was mainly a night time phenomenon brought about by the strong downward transport of momentum induced by mechanical turblulence above the city, which at times of light winds more than compensates for increased surface friction by the buildings. Bornstem *et al.* (1972) showed that in winds of less than 4m/s, there was a 20 per cent increase in speeds over the city, the greatest increases occurring in winds of less than 1.3 m/s. Johnson and Bornstein (1974) found evidence of cyclonic curvature of wind over New York in strong winds and anticyclonic in light.

In the present study, it is observed (Fig. 4) that the winds are either calm or light in the suburbs but accelerated towards warm pocket/heat island region to 10 kmph. Secondly, the wind speeds being low, showed an anticyclonic curvature particularly on 23-24 March 1978 similar to extratropical urban climatic studies 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.

The heat island has a number of consequences. In cold regions it reduces the number of heating degree days. In warm regions or seasons the heat island contributes to discomfort and increases the cooling requirements. With a view to assess the effect of heat island on comfort or discomfort it could cause in Delhi and environs, climograms of rural and urban Delhi at the maximum and minimum temperature epochs are shown in Figs. 5 and 6. The central shaded area indicates roughly a comfortable environment. For each month of the year the mean daily maximum temperature has been plotted against the mean minimum relative humidity to give an indication of the average effective temperature during the heat of the day. Similarly, the mean daily minimum temperature has been plotted against the maximum relative humidity to give the effective temperature during the cool of the night. They are compared with the 'zone of thermal comfort'. This is based on the summer comfort zone given in the American Heating and ventilating Engineers Guide for air-conditioning buildings in the United States (Atkinson 1952). Though,

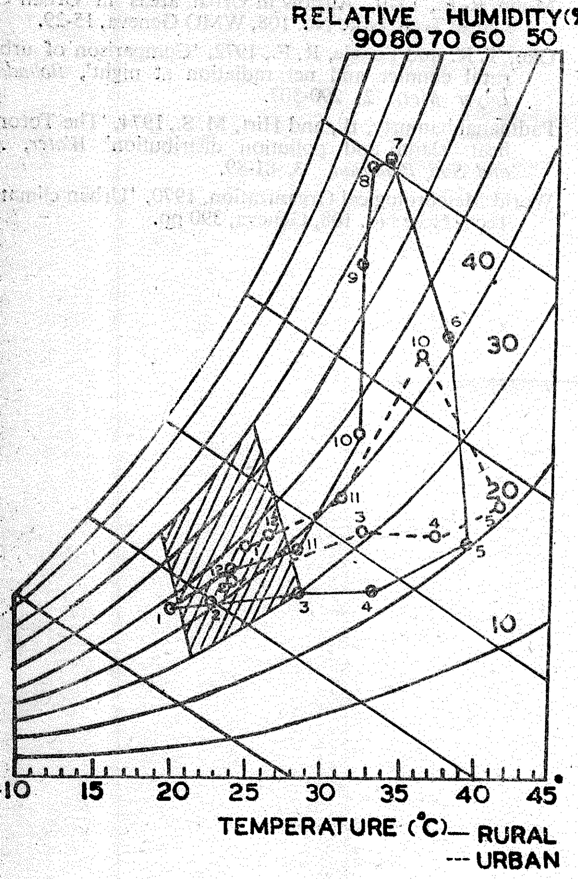

Fig. 5. Climogram of Delhi at maximum temperature epoch

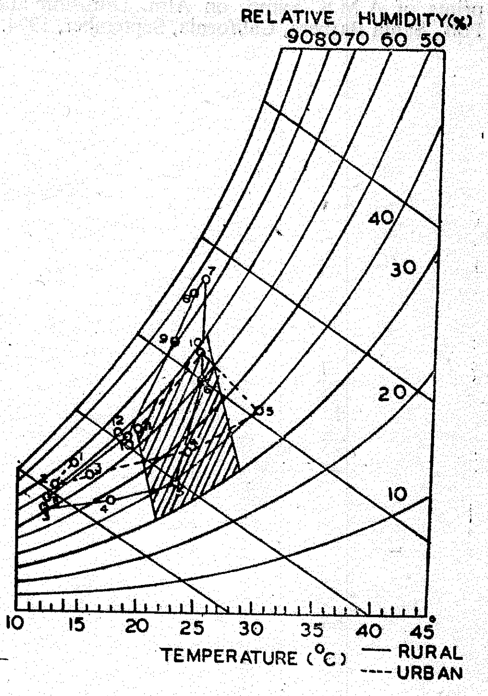

Fig. 6. Climogram of Delhi at minimum temperature epoch

obviously, not directly applicable to tropical countries, it is a useful approximation and may serve until more is known about the physiological behaviour of tropical people.

Daytime conditions show that February, March and December are comfortable in rural Delhi but in Urban Delhi January, February and December are comfortable. The heat island in January enabled urban Delhi to be comfortable but rural Delhi remains uncomfortable on the colder side. From April to November rural Delhi is uncomfortable on the hotter side. Urban Delhi is uncomfortable from March to November.

Considering night time conditions rural Delhi is comfortable in May, June only. July, August and September are uncomfortable on the hotter side and January to April and October to December are uncomfortable on the colder side. At urban Delhi because of heat island April, October and November are comfortable. May to September and December, January to March are uncomfortable on the hotter and colder sides respectively.

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