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Assimilative capacity of the atmosphere at Lucknow with respect to air pollution

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सार — उत्तर प्रदेश की राजधानी, लखनऊ में सामयिक संभावित और दैनिक प्रदूषण का इसमें अध्ययन किया गया है। प्रदूषण की संभावना का आंकलन करने के लिए, लखनऊ की चार ऋतुओं, शीत ऋतु (दिसम्बर-फरवरी), ग्रीष्म ऋतु (मार्च-मई), द. प. मानसून ऋतु (जून-सितम्बर) और मानसून के बाद की ऋतु (अक्तूबर-नवम्बर) के, पांच वर्षों की अवधि (1982-86) के आँकड़ों का विश्लेषण किया गया है। ऋतुवार वातकमल, वात गतिहीनता और वात गतिहीनता कमल तैयार किए गए तथा भिन्न ऊँचाइयों और संवातन गुणांक के ऋतुवार दैनिक परिवर्तन का भी विस्तार से अध्ययन किया गया है। यह पता चला कि लखनऊ में ग्रीष्म ऋतु में प्रदूषण की संभावना अधिक और शीत ऋतु में कम है। ऊर्ध्वाधर मिश्रण के लिए अपराह्न का समय बेहतर है। सभी ऋतुओं में पवन पश्चिम से उत्तर दिशा की तरफ बहती है, केवल मानसून ऋतु में पवन पूर्व दिशा से आती है।

ABSTRACT. The present study aim at seasonal and diurnal pollution potential at Lucknow, the capital of Uttar Pradesh. To assess the pollution potential, meteorological data for five year period (1982-86) of Lucknow have been analyzed for four season, *viz;* Winter (December-February), Summer (March-May), Southwest Monsoon (June-September) and Post Monsoon (October-November). Seasonwise wind roses, stability, stability wind roses have been prepared and season wise diurnal variation of mixing height and ventilation coefficient have also been worked out. It is found that Lucknow has a better diffusion capacity in summer and poor in winter. Afternoon hours are better for vertical mixing. The winds are predominant from west to north direction in all season except in monsoon where it blows from east direction.

Key words—Windrose, Mixing heights, Ventilation coefficient, Stability, Pollution potential.

1. Introduction

The assimilative capacity of the atmosphere over a place is determined by dilution and dispersion of the pollutants. Air pollution climatology explains the ability of the atmosphere to dilute, disperse or stagnate the pollutants over a place at any time. Wark and Warner (1976) have stated that the pollution level at any place and time represents the balance between rate of emission from their sources and the rate at which they are removed from the atmosphere. Lucknow is the capital of Uttar Pradesh and facing enormous atmospheric pollution problem due to rapid industrialization and increase in vehicular activity. Thus it is aimed to assess the assimilative capacity of the atmosphere over Lucknow with respect to pollution which may be useful for identification of areas for new industrial set up; an urban planning and air quality management.

2. Data and method of analysis

To identify the role of climatic factors in diffusion of air pollutants released in the atmosphere over Lucknow, variation of wind, stability, mixing height and ventilation coefficient have been worked out. The meteorological data of Lucknow for the five year period (1982-86) have been used in this study. Daily upper air data recorded at 0530 hrs (IST) have been used for computation of mixing height and ventilation coefficient. Daily surface data containing wind, cloud and temperature recorded at every three hours have been also utilized for preparation of wind rose, stability and mixing height and ventilation coefficient. Three hourly surface wind data has been sorted out season wise for four seasons, *viz;* Winter (December to February), Summer (March to May), Monsoon (June to September) and Post Monsoon Season (October to November).

On preliminary analysis, it is found that no significant diurnal variation has been observed in wind. Therefore a sixteen point wind rose for individual season has been prepared. Seasonwise surface meteorological data has been sorted out and a Pasquill Stability Classes were determined by using Turner's (1964) method for every synoptic hours.

TABLE 1

Percentage frequency of stability classes at Lucknow

Time (IST)	Percentage frequency stability class						
	A	B	C	D	E	F	G
				Winter			
0230	0.0	0.0	0.0	2.1	6.7	19.8	71.4
0530	0.0	0.0	0.0	4.7	4.3	15.8	75.2
0830	8.4	10.3	18.8	6.25	0.0	0.0	0.0
1130	65.6	10.5	7.1	16.8	0.0	0.0	0.0
1430	57.4	20.4	7.2	15.0	0.0	0.0	0.0
1730	0.0	0.0	92.3	7.7	0.0	0.0	0.0
2030	0.0	0.0	0.0	0.0	2.0	20.1	77.9
2330	0.0	0.0	0.0	0.9	2.2	15.0	81.9
				Summer			
0230	0.0	0.0	0.0	7.6	15.0	27.1	50.3
0530	0.0	0.0	0.0	5.6	11.4	24.2	58.8
0830	13.7	53.5	24.0	8.8	0.0	0.0	0.0
1130	41.0	38.2	15.4	5.4	0.0	0.0	0.0
1430	3.5	35.6	31.3	29.6	0.0	0.0	0.0
1730	0.0	0.0	34.0	66.0	0.0	0.0	0.0
2030	0.0	0.0	0.0	6.5	9.1	21.3	63.1
2330	0.0	0.0	0.0	11.9	12.2	26.1	49.8
				Monsoon			
0230	0.0	0.0	0.0	33.2	13.3	41.0	12.5
0530	0.0	0.0	0.0	34.0	11.7	44.9	9.4
0830	0.0	37.6	14.2	48.2	0.0	0.0	0.0
1130	4.5	11.3	7.5	76.7	0.0	0.0	0.0
1430	0.4	4.7	28.1	66.8	0.0	0.0	0.0
1730	0.0	4.2	27.8	68.0	0.0	0.0	0.0
2030	0.0	0.0	0.0	36.0	15.5	42.0	6.5
2330	0.0	0.0	0.0	34.5	13.8	40.9	10.8
				Post Monsoon			
0230	0.0	0.0	0.0	8.2	0.5	17.5	73.8
0530	0.0	0.0	0.0	7.5	1.6	26.7	64.2
0830	6.6	15.3	24.5	53.6	0.0	0.0	0.0
1130	59.2	15.0	14.7	11.1	0.0	0.0	0.0
1430	20.0	40.1	14.8	25.1	0.0	0.0	0.0
1730	0.0	0.0	0.0	9.5	2.9	23.5	64.1
2030	0.0	0.0	0.0	9.0	3.1	15.7	72.2
2330	0.0	0.0	0.0	8.4	2.3	18.5	70.8

A - Extremely Unstable, B - Moderately Unstable,
C - Slightly Unstable, D - Neutral,
E - Slightly Stable, F - Moderately Stable,

Season wise upper air data at 0530 hrs (IST) have been sorted out separately and plotted on T-ϕ gram. Daily upper air data at 0530 hrs (IST) have been used for computation of mixing height and ventilation coefficient. Mixing height is determined by extending a dry adiabat from surface temperature to its intersection with the morning temperature sounding (Holzworth, 1967). The height of the point of intersection from ground is termed as mixing height. The mixing height at every synoptic hour has beem computed by extending the dry adiabat from the surface temperature corresponding to the given synoptic hour to intersect morning sounding through the standard time. The daily mixing height at every synoptic hours have been calculated and averaged out at every synoptic hours in season wise fashion. The ventilation coefficient at any time can be obtained by multiplying the mixing height at that time and the mean wind speed through the mixing layer. The ventilation coefficient computed daily for every synoptic hours and a seasonal average ventilation coefficient have been worked out.

3. Results and discussion

3.1. *Wind*

The season wise wind roses have been prepared and presented in Fig. 1. Generally, the frequency of occurrence

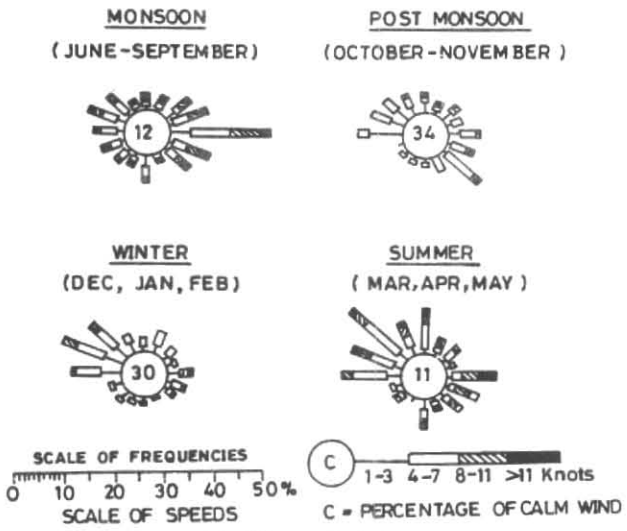


Fig. 1. Seasonal wind roses

of calm periods are higher in post monsoon (34%) followed by winter (30%) and lesser in summer (11%) followed by monsoon season (12%). In winter and post monsoon season, the wind speed rarely exceeds 11 knots, and frequently exceeds 11 kts in summer and monsoon season. The predominant winds are from west to northwest and from east to southeast in all season, except in winter when winds mostly blow from west to northwest. Generally, winds blowing from east to southeasterly direction are stronger compared to the winds blowing from west to northwesterly direction. Winds not only determine the travel time of pollutants from the source to a given receptor but also the ground level concentration. The calm winds/weaker winds will deteriorate air quality. Thus, better dispersal of pollutants is expected in summer and poor in winter season.

3.2. *Stability*

The percentage frequencies of occurrence and the seven stability classes during every synoptic hours in four season have been computed and presented in Table 1. It is noticed that unstable conditions during night time and stable condition during day time have not occurred in all the season. In winter, "A" (highly unstable) condition are more frequent at 1130 and 1430 hrs (IST); "B" (moderately unstable) condition are also frequent at 1430 hrs (IST) and "C" (slightly unstable) conditions at 1730 hrs (IST); "D" (neutral) condition are more frequent at 0830 hrs (IST) and less during night hours. "E" (slightly stable) condition are more frequent at 0230 hrs (IST) and "F" (moderately stable) condition at 2030 hrs (IST), "G" (highly stable) condition is also more frequent at 2330 hrs (IST). In general, winter season experiences maximum frequency of "G" stability classes during night time. In summer, "A" stability conditions are more frequent at 1130 hrs (IST), "B" stability condition at 0830 hrs (IST) and "C" stability condition at 1730 hrs (IST). However "D" stability conditions occurred at all synoptic hours and are more frequent at 1730 hrs (IST). "E" and "F" conditions are more frequent at 0230 hrs (IST) and "G" condition at 2030 hrs (IST). In monsoon, "A" conditions rarely occurred at 1130 hrs (IST). However "B" and "C" conditions occurred in all synoptic hours during day time and are more frequent at 0830 and 1430 hrs (IST) respectively. "D" stability has occurred in all synoptic hours during day and night time. "D" stability is more frequent at 1130 hrs (IST) during day time and at 2030 hrs (IST) during night time. "E" stability are more frequent at 2030 hrs (IST) and "F" at 0530 hrs and "G" at 0230 hrs (IST). In general, the frequencies of occurrence of "G" stability in this season are less compared to other season. In post monsoon, "A" stability is more frequent at 1130 hrs (IST), "B" stability at 1430 hrs (IST) and "C" stability at 0830 hrs (IST). "D" stability condition have occurred in all the synoptic hours during day and night time with maximum frequency at 0830 hrs (IST). "E" condition are less frequent compared to "F" and "G" condition during night time. "F" condition are more frequent at 0530 hrs (IST) and "G" condition at 0230 hrs (IST).

Highly unstable conditions have occurred at 1130 and 1430 hrs (IST) with high frequencies in all season except monsoon. Highly stable condition have occurred during night time especially after 2030 hrs (IST). The other conditions are less frequent in all the seasons. The neutral conditions are more frequent in monsoon compared to other season. Therefore, an efficient dispersion of pollutants during day time in all the months can be expected. Of the four season; better diffusion of pollutants can be expected during summer and monsoon season.

3.3. *Stability wind roses*

From the winds during the three stability classes (A-C, D,E-G) both at day and night time stability winds roses have been prepared and presented in Fig. 2.

In winter, during day time 29% and 4% of calm periods during unstable and neutral condition have been observed. The winds predominantly blows from west to north direction. During night-time, 38% and 55% of calm periods have been observed respectively during neutral and stable condition. The predominant winds are from west to north under neutral and stable condition.

In summer, during day time 9% and 2% calm periods have been observed under unstable and neutral condition respectively. The dominant winds are from northwest to north direction under both conditions. During night time, 13% and 60% of calm period have been observed under neutral and stable condition. The dominant winds are northwest to north direction under both the condition. Weaker winds have observed under stable condition during night

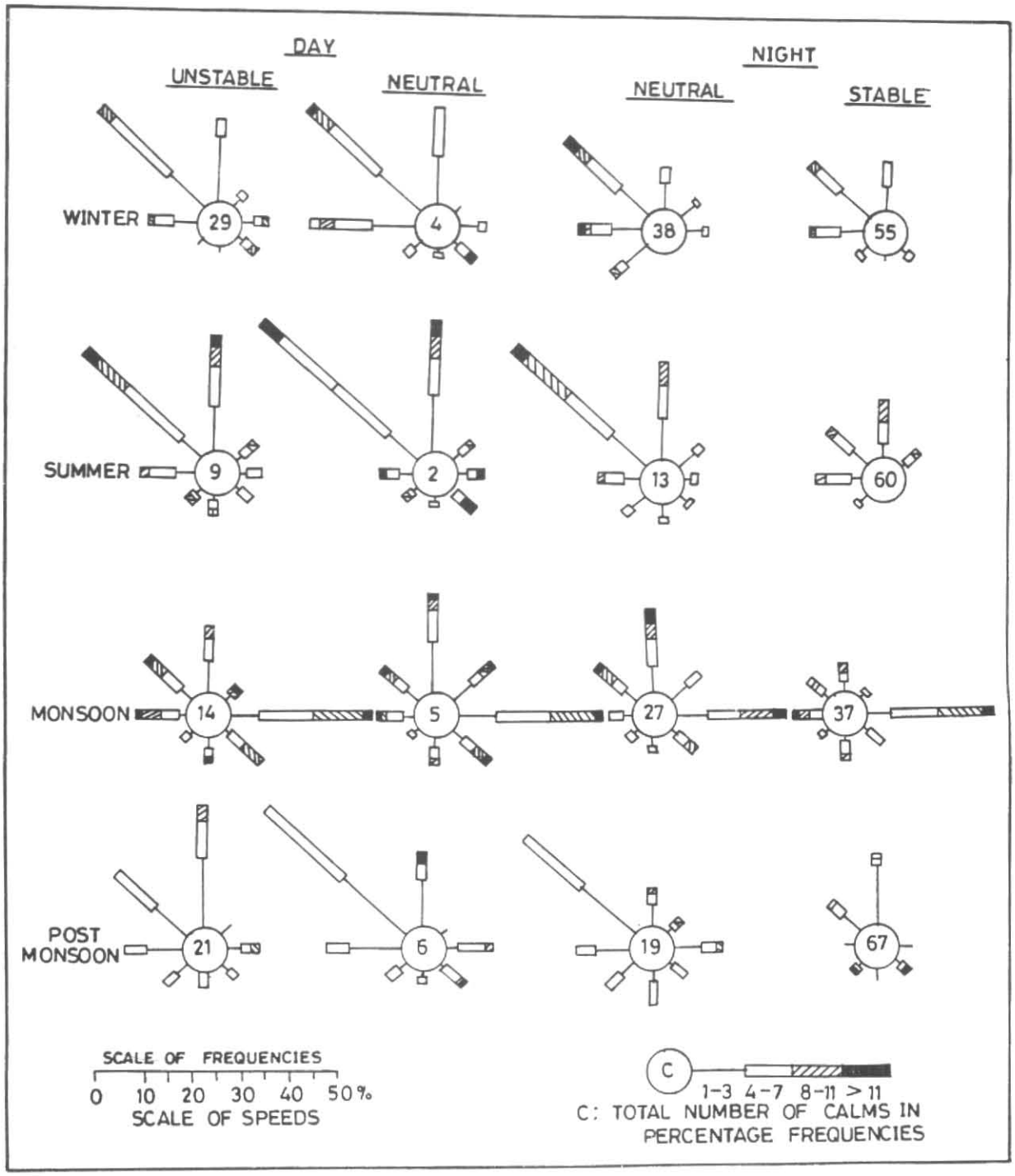
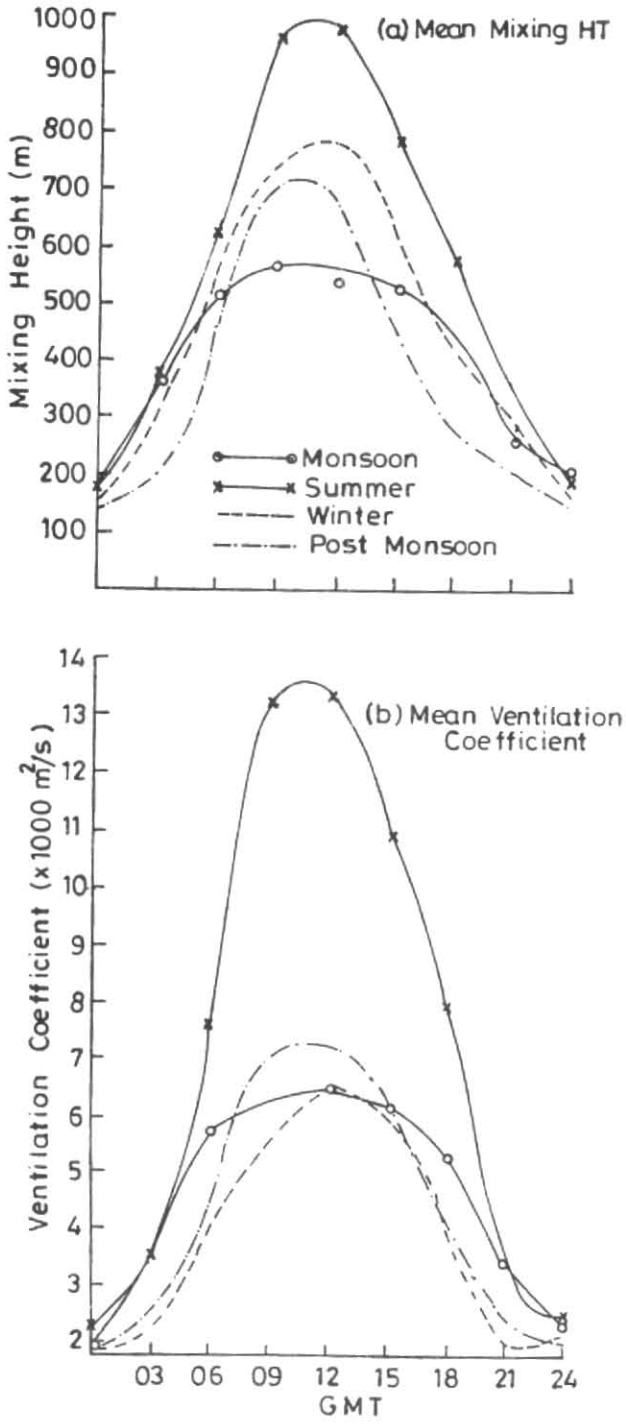


Fig. 2. Stability wind roses

time stronger winds under unstable and neutral condition during day time.

In monsoon during day time, 14% and 5% calm periods have been observed under unstable and neutral condition respectively.

The dominant winds are easterlies and to the some extent northerly under both condition. During night time, 27% and 37% of the calm period have been observed under neutral and stable condition respectively. The predominant winds are easterlies under both conditions and to the some extent northerly under neutral condition.



Figs. 3(a & b).(a) Mean mixing heights and (b) mean ventilation coefficient over Lucknow

In post monsoon, during day time, 21% and 6% calm period have been observed under unstable and neutral condition respectively. The predominant winds are west to north direction under both the condition. During night time, 19% and 67% of calm period have been observed under neutral and stable conditions respectively. The predominant winds are north westerlies under neutral condition and northwest to north direction under stable condition.

Maximum calm periods have been observed under stable condition during night time and minimum under neutral condition during day time. It is therefore concluded that poor diffusion condition exist during night time in all season. It can be also concluded that better diffusion condition exists in summer and monsoon season.

3.4. *Mixing height and ventilation coefficient*

Diurnal variation of mean mixing height and ventilation coefficient have been calculated and presented in Figs. 3(a&b). The highest afternoon mixing height have been observed in summer and lowest in monsoon season. The highest mixing height observed between 1430 & 1730 hrs (IST) and lowest during late night. The amplitude of diurnal variation of mixing height in summer is not larger and in winter is small. Winter and post monsoon season do not shows any significant variation in mixing height.

The highest ventilation coefficient have been observed in summer and lowest in monsoon followed by winter. The highest ventilation coefficient observed between 1430 & 1730 hrs (IST) and lowest during late night. The amplitude of diurnal variation of ventilation coefficient in summer is also large compared to other season. No significant diurnal variation in ventilation coefficient have been observed in monsoon, winter and post monsoon season. The afternoon ventilation coefficient in summer is almost double than that observed in any other season. By applying Gross (1970) criteria of forecasting high pollution potential in this study; it is found that Lucknow has high pollution potential in late night to early morning hours in all seasons, which gradually decreases during noon hours and eventually disappears in the afternoon/early evening. Therefore, a good vertical mixing of contaminants is expected in the afternoon/evening hour and poor in late night in all season. Good vertical mixing of contaminants and better ventilation is also expected in summer.

4. Conclusion

More calm winds have been observed in winter and less in summer season. The winds are dominant from west to northwest direction. Thus, it is inferred that better diffusion capacity exist in summer and poor in winter. No major polluting industries should be set up west to northwest sector of the city. Highly unstable conditions are more frequent at mid-day and stable conditions are in winter and post monsoon season. Stability wind roses also shows maximum calm winds under stable condition during night time and minimum under neutral condition during day time. Thus it is

concluded that poor diffusion condition exists during night time in all season. It is also concluded that better diffusion condition exists in summer and monsoon season.

Highest afternoon mixing height and ventilation coefficient occurred in summer. Lucknow has got high pollution potential in the night to early morning hours in all seasons, which gradually decrease, in noon hours and eventually disappear in the afternoon/early evening hour. Therefore, it is concluded that good vertical mixing and better ventilation of contaminants is expected in the afternoon/evening hours and poor in late night in all season. It is also concluded that summer season has got a better diffusion capacity.

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