Mausam, (1993), **44**, 2, 199-204

551.510.42 : 551.583.13

Dispersion climatology for Patna and Gaya

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(Received 12 May 1992, Modified 17 August 1992)

सार — इस अध्ययन का उद्देश्य बिहार तथा गया के राजधानी क्षेत्र पटना के आस-पास मौसमवार और दैनिक प्रदूषण विभव पर विचार करना है। प्रदूषण विभव का निर्धारण करने के लिए दो केन्द्रों, पटना तथा उसके पास स्थित गया के पांच वर्ष की अवधि (1984-88) के मौसम आंकड़ों का विश्लेषण किया गया है। चार प्रतिनिधि मौसमवार महीनों अर्थात् शीतकाल (जनवरी), मानसून पूर्व (अप्रैल), मानसून (अगस्त) तथा मानसूनोपरान्त (अक्तूबर) का विश्लेषण किया गया।

इस विश्लेषण से प्रत्येक महीने में दिन के समय किसी स्थिर अवस्था का पता नहीं चला है और न रात के समय कोई अस्थिर अवस्था दिखाई दी। अस्थिर अवस्थाओं की उच्चतर आवृत्तियां अप्रैल में तथा न्यूनतम आवृत्तियां जनवरी में पाई गईं। अप्रैल में मिश्रण ऊंचाई और संवातन गुणांक अधिकतम होता है। परिणाम से यह निष्कर्ष निकाला गया है कि सभी महीनों में दिन का समय अच्छे विक्षेपण के लिए उपयुक्त है। वर्तमान औद्योगिक क्षेत्रों में उत्सर्जन रात के समय विशेषकर शीतकालीन महीनों के दौरान कम करना चाहिए। यह परिणाम यह भी जानकारी देते हैं कि अप्रैल और अगस्त में प्रदूषण काफी फैले रहते हैं। जनवरी और अगस्त प्रदूषकों के उर्ध्वाधर विसरण के लिए सबसे माह अनुपयुक्त हैं। प्रबल सतह पवनें पूर्वी होती हैं इसलिए प्रदूषकों के प्रभावों को कम करने के लिए नए उद्योग को शहर के पश्चिम में स्थापित करना चाहिए।

ABSTRACT. The present study aims at seasonal and diurnal pollution potential around Patna, the capital region of Bihar and Gaya. To assess the pollution potential, meteorological data of two stations, *viz.*, Patna and the neighbouring station Gaya for five year period (1984-88) have been analysed. The analysis has been done for four representative seasonal months, *viz.*, winter (January), pre-monsoon (April), monsoon (August) and post-monsoon (October).

The analysis shows no stable conditions in the day time and no unstable condition in the night time in each month. April shows higher frequency and January the lowest frequencies of unstable conditions. April has the highest mixing height and ventilation coefficient. From the results it has been concluded that day time is suitable for good dispersion in all the months. In the case of existing industries, emission must be lessened during night time and particularly in the winter months. These results also suggest that pollutants are well dispersed in April and August. January and August may be regarded as the worst months for vertical diffusion of contaminants. As the predominant surface winds are easterly, any new industrial set up should be in the west of the city in order to minimise the effects of pollutants.

Key words — Pollution potential, Wind roses, Stability, Inversion, Mixing height, Ventilation-coefficient, Emission schedule.

1. Introduction

Patna (Lat. 25° 36′ N; Long. 85° 06′ E; altitude 53 m amsl), the capital of Bihar is facing enormous environmental problems particularly atmospheric pollution. Patna is a very long city, indeed a linear city between the fangs of two rivers, namely, the *Ganga* on the north and the *Poonpoon* on the south. The neighbouring station Gaya (Lat. 24° 48′ N; Long. 85° 30′ E; altitude 116 m amsl) is situated on the bank of *Phalgu* river. The pollution level at any place and time represents balance between the rate of emission from their sources and the rate at which they are removed from the atmosphere (Wark and Warner 1976). For a particular region and time level of pollution depends upon the rate of emissions and the existing meteorological conditions. The assimilative capacity of the atmosphere determines the dilution and dispersion of the pollutants.

Air pollution climatology explains the ability of the atmosphere to dilute or stagnate pollutants over a region at any time. The most important uses of air pollution climatology are urban planning, industrial location in relation to sensitive areas and air quality management. The different parameters involved in this type of study are the temporal and spatial variation of wind, stability, inversion, mixing height, ventilation coefficient etc.

2. Material and method

The present study aims to identify the role of climatic factors in the diffusion of air pollutants released in the atmosphere over the capital region of Bihar (Patna) and Gaya. For this purpose the meteorological data of two stations, *viz.*, Patna and the neighbouring station Gaya for five year period (1984-88) have been made use

TABLE 1

Percentage frequency of stability classes at Patna

Time (GMT)	Percentage frequency stability class						
	A	B	C	D	E	F	G
				January			
0000	0.0	0.0	0.0	4.5	3.9	16.1	75.5
0300	14.8	2.8	13.8	68.9	0.0	0.0	0.0
0600	64.4	10.9	5.4	19.2	0.0	0.0	0.0
0900	60.1	17.6	6.6	15.7	0.0	0.0	0.0
1200	0.0	0.0	92.7	7.2	0.0	0.0	0.0
1500	0.0	0.0	0.0	0.7	0.7	15.0	83.6
1800	0.0	0.0	0.0	1.3	1.9	13.6	83.2
2100	0.0	0.0	0.0	1.3	6.8	22.3	69.6
				April			
0000	0.0	0.0	0.0	4.7	16.8	26.2	52.3
0300	8.1	53.0	28.8	10.1	0.0	0.0	0.0
0600	35.9	38.8	18.7	6.7	0.0	0.0	0.0
0900	3.1	35.9	35.1	25.9	0.0	0.0	0.0
1200	0.0	0.0	34.7	65.3	0.0	0.0	0.0
1500	0.0	0.0	0.0	7.5	10.8	22.3	59.4
1800	0.0	0.0	0.0	18.8	14.5	27.6	39.1
2100	0.0	0.0	0.0	8.0	15.3	27.4	49.3
				August			
0000	0.0	0.0	0.0	26.8	13.0	47.1	13.1
0300	0.0	42.1	13.8	44.1	0.0	0.0	0.0
0600	4.7	9.4	1.4	84.5	0.0	0.0	0.0
0900	0.7	7.2	23.2	68.9	0.0	0.0	0.0
1200	0.7	7.4	23.6	68.3	0.0	0.0	0.0
1500	0.0	0.0	0.0	23.9	22.6	41.9	11.6
1800	0.0	0.0	0.0	23.0	17.1	44.1	15.8
2100	0.0	0.0	0.0	24.1	18.2	39.6	18.1
				October			
0000	0.0	0.0	0.0	5.2	1.9	24.0	68.9
0300	1.4	13.6	27.2	57.8	0.0	0.0	0.0
0600	56.6	7.4	2.9	33.1	0.0	0.0	0.0
0900	28.9	33.4	16.6	21.0	0.0	0.0	0.0
1200	0.0	0.0	0.0	5.9	1.9	30.9	61.3
1500	0.0	0.0	0.0	6.5	1.9	15.5	76.1
1800	0.0	0.0	0.0	3.9	3.3	20.3	72.5
2100	0.0	0.0	0.0	5.2	1.9	20.0	72.9

TABLE 2

Percentage frequency of stability classes at Gaya

Time (GMT)	Percentage frequency stability class						
	A	B	C	D	E	F	G
				January			
0000	0.0	0.0	0.0	7.1	0.0	20.0	72.9
0300	0.0	70.3	23.8	5.9	0.0	0.0	0.0
0600	67.1	20.0	8.4	4.5	0.0	0.0	0.0
0900	12.9	53.6	18.7	14.8	0.0	0.0	0.0
1200	0.0	0.0	85.2	14.8	0.0	0.0	0.0
1500	0.0	0.0	0.0	3.2	0.7	25.3	70.8
1800	0.0	0.0	0.0	5.9	0.6	16.5	77.0
2100	0.0	0.0	0.0	3.9	1.3	16.2	78.6
				April			
0000	0.0	0.0	0.0	6.0	6.0	22.3	64.7
0300	19.3	54.0	19.3	7.4	0.0	0.0	0.0
0600	60.4	23.5	12.0	4.1	0.0	0.0	0.0
0900	4.0	35.3	27.4	33.3	0.0	0.0	0.0
1200	0.0	0.0	33.3	66.7	0.0	0.0	0.0
1500	0.0	0.0	0.0	5.4	7.4	20.3	66.9
1800	0.0	0.0	0.0	4.0	10.0	24.0	62.0
2100	0.0	0.0	0.0	6.1	4.7	28.8	60.4
				August			
0000	0.0	0.0	0.0	41.3	10.3	42.6	5.8
0300	0.0	5.1	42.6	52.3	0.0	0.0	0.0
0600	5.2	32.9	33.5	28.4	0.0	0.0	0.0
0900	0.0	2.2	33.1	64.7	0.0	0.0	0.0
1200	0.0	0.0	32.3	67.7	0.0	0.0	0.0
1500	0.0	0.0	0.0	48.1	8.5	42.1	1.3
1800	0.0	0.0	0.0	46.1	10.4	37.7	5.8
2100	0.0	0.0	0.0	42.2	9.1	42.9	5.8
				October			
0000	0.0	0.0	0.0	9.7	1.3	33.5	55.5
0300	11.8	57.2	21.7	9.3	0.0	0.0	0.0
0600	61.9	22.6	10.3	5.2	0.0	0.0	0.0
0900	11.0	46.8	13.0	29.2	0.0	0.0	0.0
1200	0.0	0.0	70.3	29.7	0.0	0.0	0.0
1500	0.0	0.0	0.0	11.6	3.9	16.1	68.4
1800	0.0	0.0	0.0	12.9	1.3	16.7	69.1
2100	0.0	0.0	0.0	11.2	0.0	30.9	57.9

A — Extremely unstable, B — Moderately unstable, C — Slighly unstable, D — Neutral,
E — Slightly stable, F — Moderately stable, G — Extremely stable.

The state of the above atmospheric classification is based on latitude, cloudiness and wind speed. In this system extreme instability is associated with maximum diffusion of pollutants. Inhibition of turbulence associated with inversions and calm periods leads to stable atmosphere. The intermediate stage between these two is neutral atmosphere which slides towards instability in one side and the stability on the other.

of. Of these two stations, Patna is an industrial-residential-commercial whereas, Gaya is mainly a residential-commercial area. The analysis has been done for four representative seasonal months corresponding to seasons, *viz.,* winter (January), pre-monsoon (April), monsoon (August) and post-monsoon (October).

3. Results and discussion

3.1. *Wind*

Wind roses for the representative months have been presented in Figs. 1(a-d). The frequencies of calm periods are higher for Patna than Gaya except in the month of April. Gaya has minimum calm conditions and higher winds which may be due to the surrounding hills in contrast to Patna.

January and October which represent the winter and post-monsoon periods have more calm periods. Minimum number of calm periods are observed during the month of April (pre-monsoon). The topographic features at Gaya distinct from Patna always causes differences in the patterns of meteorological parameters. Of the four months, calm periods are (64%) in January and October at Patna and highest (58%) in January at Gaya. Wind speeds reached up to 10 kt in January, and up to 16 kt in April, but rarely reached up to 16 kt in October for both the stations. In the month of August it exceeded 16 kt for Gaya whereas it reached up to 16 kt for Patna.

It has been found at both the stations that easterly winds are predominant in every month except January where west to northwesterly winds are predominant. Present study shows that all the moderate and strong winds in Patna are from west to northwest in January, from east to eastnortheast in April, east to northnortheast in August and east to southeast direction in October. For Gaya winds are from west to northwest in January and April, east to northeast in August and west to northwest in October.

Winds not only determine the travel time of pollutants from the source to a given receptor but also their concentrations on the ground. Calm periods will cause air quality to deteriorate and very strong winds may cause more ground level concentration (Munn 1976). However, higher wind speeds can transport the pollutants over long distances. From the present study, April and August can be expected to have a high capacity for the dispersal of pollutants, whereas January and October have the minimum capacity. It can be expected from the present study that Gaya will face less pollution problem from any new industrial set up than Patna. The predominant winds are easterly, so any new industrial set up should be in the down wind direction (*i.e.,* west of city) in order to minimise the effects of pollutants.

3.2. *Stability*

Pasquill stability classes were determined using Turner's (1964) method for every synoptic hour. The percentage frequencies of seven stability classes during every synoptic hour in the four months at both the stations have been computed and separately presented in Tables 1 & 2.

Unstable conditions during night time and stable conditions during day time were not observed in any of the four months at both stations. Although the neutral stability condition "D" occurred during both day and night, but its frequency was very much less during night time for both the stations in all the months.

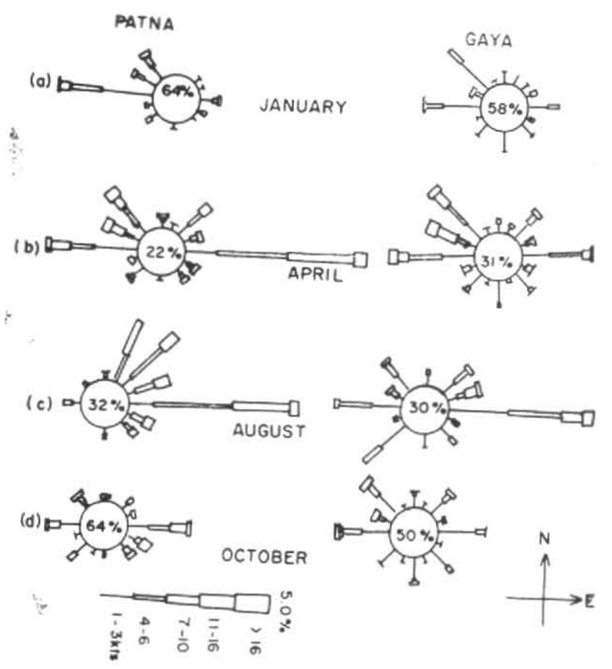
Except in April, Patna experienced more frequencies of highest (G) stability class than Gaya. Highly unstable conditions have been occurred at 0600 GMT for all the months at both the stations. August month is characterised by more neutral stability condition at both stations which is typical of monsoon season. The trend of percentage frequencies of stability class is very similar to that of winter, pre-monsoon, monsoon and dost-monsoon months with slight variation.

Thus, it can be expected from the present study tha the dispersion capacity at Patna is higher than at Gaya because of comparatively more unstable condition at Patna. The decrease in turbulence intensity by an order of magnitude as a stability class goes from "A" through "F" (Luna and Church 1972, Ogawa *et al.* 1985). Hence, more turbulence will accompany with unstable condition at Patna. Highly unstable conditions occurred more frequently in the afternoon. Stable conditions occurred more frequently in January and October, even stability class "G". Efficient dispersion of pollutants during day time can be expected particularly in April and August whereas poor dispersion is expected at night time especially in January and October.

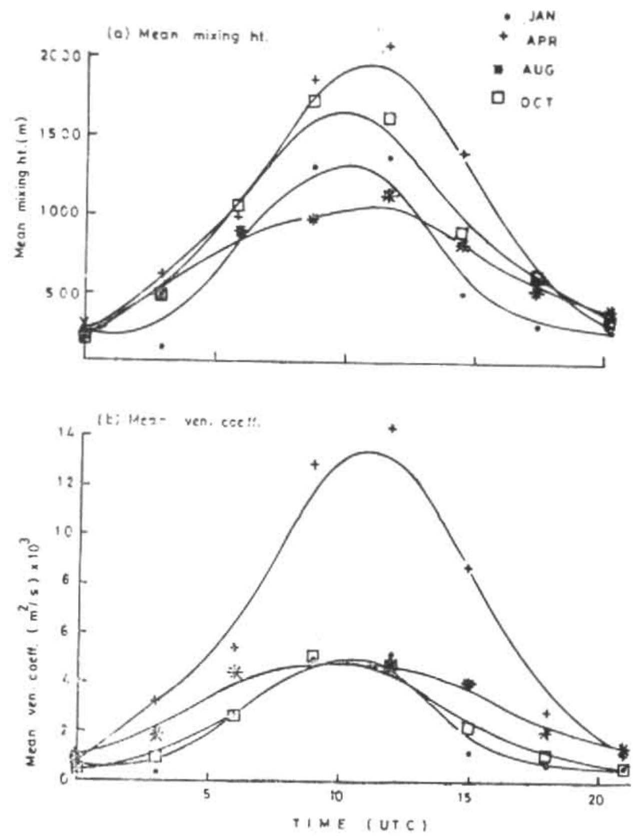
3.3. *Inversion*

Percentage frequencies of ground inversions and ground based inversions with various top heights have been computed for Patna at 0000 GMT and 1200 GMT and separately presented in Tables 3 & 4. The radiosonde data of Patna available for the period 1984-1988 were analysed.

For the study of percentage frequencies distribution of inversions, the atmosphere within the planetary boundary layer (1.5 km) have been considered. The frequencies have been rounded off to the whole number to the nearest number. Patna shows highest frequencies of inversion layers in the month of January (68%) followed by April (48%). Extremely low value is found in the month of August (7%). In October (40%) it has increased again. In January high inversions are formed due to nocturnal cooling during clear nights and very low winds prevailing at this place. The minimum frequency in August is supposed to be due to cloudy



Figs. 1 (a-d). Seasonal wind roses



Figs. 2(a&b). (a) Mean mixing heights and (b) mean ventilation coefficient over Patna

weather. Ground based inversions with various top heights reveal that maximum frequencies of the inversions occur nearly at heights between 0-200 m, 400-600 m and 900-1100 m.

Frequencies of ground inversion layers and ground based inversions with various top heights at 1200 GMT are very low. Results show that most of the inversions terminate at height 600 m.

Ground based inversions limit the dispersion of pollutants vertically. The top of inversion acts effectively as a lid and traps any pollutants released below it. Thus we may conclude in considering inversions, with foregoing principle, of all the months, January may be the worst for mixing of pollutants whereas, August is better in the studied area.

3.4. *Diurnal variation of mean mixing heights and mean ventilation coefficients*

The diurnal variations of mean mixing heights and mean ventilation coefficients have been presented in Figs. 2(a & b) for Patna only because radiosonde data is not available for Gaya. Among the four months, the highest afternoon mixing height occurred in April followed successively by October, January and August. In April the highest mixing height value can be explained to be due to maximum surface heat. The percentage frequency of occurrence of low mixing heights are maximum in winter due to surface based inversion.

The minimum mixing height has been observed at 0300 GMT in January and at 0000 GMT in rest of the months. The maximum mixing height has been observed mostly at 1200 GMT except in October when it is observed at 0900 GMT. The mixing height increases

TABLE 3

Percentage frequencies of ground inversions at Patna

Month	Time (GMT)	
	0000	1200
January	68	04
April	48	02
August	07	01
October	40	03

TABLE 4

Percentage frequencies of ground based inversions with various top heights (0000 and 1200 GMT) at Patna

Range (m)	Month			
	Jan	Apr	Aug	Dec
0000 GMT				
0-100	00	07	00	04
101-200	18	00	00	07
201-300	00	00	00	00
301-400	00	00	00	00
401-500	00	06	05	04
501-600	19	12	01	12
601-700	01	00	00	00
701-800	17	00	00	00
801-900	04	00	00	00
901-1000	09	11	00	01
1001-1250	00	05	00	08
1251-1500	00	04	01	00
>1500	00	03	00	04
1200 GMT				
0-100	00	01	00	00
101-200	03	00	00	01
201-300	00	01	00	01
301-400	00	00	00	00
401-500	00	00	01	00
501-600	01	00	00	01
601-700	00	00	00	00
701-800	00	00	00	00
801-900	00	00	00	00
901-1000	00	00	00	00
1001-1250	00	00	00	00
1251-1500	00	00	00	00
>1500	00	00	00	00

from 0300 GMT to 1200 GMT and thereafter it decreases. This is due to diurnal variation of surface temperature and the existence of morning inversion. Among the four months, the highest afternoon ventilation coefficient occurred in April followed successively by January, August and October with slight variation.

Applying Gross (1970) criteria of forecasting high pollution potential in the present study, it was found that morning periods have high pollution potential in all the seasons which decrease gradually during the day and eventually disappeared in the afternoon. Good vertical mixing of contaminants can be expected in the evenings of April. In case of August, pollutants will be removed through wet deposition, concentration of pollutants will be lower even though mixing height and ventilation coefficient values will be low. These results also suggest that pollutants are well dispersed in April and August. January and October may be regarded as the worst months for diffusion of contaminants.

4. Conclusions

Low winds were observed in January and high in April for both the stations. The predominant winds were easterly. As the dilution of pollutants depends on prevailing winds, better dispersion of pollutants is expected in April and accumulation in January. From the wind direction it can be concluded that no major polluting industry should be set up in the eastern sector of the capital region of Bihar (Patna). During the four months, good dispersion is expected in April and August whereas poor dispersion in January and October and night time of all the months. Of all the four months Patna shows highest frequencies of inversion layers in January and lowest in August. Hence January may be the worst for mixing of pollutants whereas August is better.

During the four months highest afternoon mixing height and ventilation coefficient occurred in April. Morning hours had a high pollution potential which decreased gradually with the time of day. Thus, it can be concluded from this study that pre-monsoon (April) and monsoon (August) months have a high carrying capacity of pollutants. Winter (January) and post-monsoon (October) months have less dispersal capacity. Night and early mornings hours have less dispersal capacity of pollutants due to stable atmosphere accompanied by light or no winds.

Acknowledgement

The authors acknowledge with thanks for the meteorological data of Patna and Gaya provided by the India Meteorological Department, Patna and Pune.

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