Indian J. Met. Geophys. (1973), **24**,1,15-26

551·577·59 : 677·05

Effect of steel mills on rainfall at distantly located stations

T. RAMANA RAO and BH. V. RAMANA MURTY

Indian Institute of Tropical Meteorology, Poona

(Received 16 Februray 1970)

ABSTRACT. Based on the target-control concept as in the design of conventional cloud seeding experiment, the monthly rainfall data of February and August of four raingauge stations, situated from 100 to 200 km from the Jamshedpur-Burnpur steel mills complex, have been analysed for the four successive 21-year periods commencing from 1872. Mean period decreases ranging upto 63 per cent in the February rainfall and upto 27 per cent in the August rainfall have been indicated at the target stations since the establishment of the steel industry in the region. Application of statistical tests on the ratio values of rainfall of the target to that of the control has pointed out that changes indicated in the February rainfall, in some cases, are significant. It has been argued that the process of rain development, characteristic of the winter clouds in the region, could be sensitive to effluents from the steel mills.

1. Introduction

Divergent views have been expressed about the effect of local pollution on rainfall in regions downwind. Changnon (1968) has shown that 31 per cent more precipitation occurred at La Porte which is about 50 km from the large complex of heavy industries at Chicago. But, Holzman and Thom (1970) have questioned the statistical validity of the precipitation record of La Porte as used by Changnon. Ogden (1969), searching for rainfall anomaly near the iron and steel plant of the Australian Iron and Steel Pty. Ltd., at port Kembla, has failed to establish such sizeable influence on rainfall within 120 km of the industry. However, Hobbs *et al.* (1970 a, b) have found large increases in the mean annual precipitation, exceeding 30 per cent in some cases, in regions adjacent to or downwind of pulp and paper mills and certain other industries in Washington. Thermal island created by the heat added to the atmosphere on account of the steel works in the region has been considered to be the main cause for the increase in rainfall at La Porte, whereas the comparatively few numbers of very efficient cloud condensation nuclei added to the atmosphere on account of the pulp and paper mills and other industries in the region have been cited as the cause for the increase in precipitation at Washington.

Industrial pollution appears, therefore, to influence the normal rainfall sometimes by amounts even greater than to be aspired in the present-day weather modification experiments. It is necessary, to know, therefore, as to what extent natural rainfall is being affected in those regions which have been under the influence of large industrial complexes and which also frequently face shortages of natural rain. Such information will be of use while planning weather modification experiments in any of those regions and also while considering setting up similar industries in new regions. As rainfall data for sufficiently long periods, both prior and subsequent to the setting up of the industry, are required for a proper investigation, the study becomes naturally restricted only to those regions for which such long-period rainfall data are available.

The effect of industrial pollution on rainfall has not been specifically examined for the Indian stations although a number of studies have been made on the secular trends and variations in rainfall for various regions of the country. While such studies made by the earlier investigators, *viz.*, Pramanik and Jagannathan (1953) and Rao and Jagannathan (1963), have not shown tendency for increase or decrease of rainfall at any of the stations or areas, it is interesting to note that a recent study by Koteswaram and Alvi (1969) has revealed that the rainfall of certain west coast stations has increased by 30 to 35 per cent during the present century. The role of local pollution on such large changes noticed in rainfall is not known. While no attempt is made here to examine the issue with reference to the west coast stations, which usually do not face shortages of natural rain, it is felt that the question should be readily examined in the case of inland stations where rainfall is less (need for additional rain by cloud seeding exists in such cases) and where industries have been existing in the vicinity. In view of the fact that the premier steel works of the country having the longest standing have been situated at Burnpur (23°41′N, 86° 59′E) in West Bengal State and at Jamshedpur (22° 49′N, 86° 11′E) in Bihar State and also keeping in view that steel works, as demonstrated by Telford (1960) and by Langer (1968), could be prolific sources of ice-forming nuclei which might in turn have profound influence

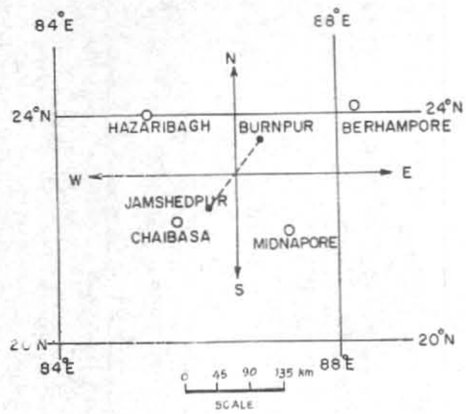

Fig. 1

Locations of raingauge stations with respect to Jamshedpur-Burnpur Steel mills complex

on the rain yield form clouds in the region, a study is undertaken in the following to see whether this steel mills complex on account of any such possible effect of the effluents from it has been influencing the rainfall of that region. As the nearest of the suitable raingauge stations, under the control of the India Meteorological Departmet, for which long period rainfall data are available, are situated at 100 to 200 km distance from the steel mills complex, the present study is limited to such distantly located stations from the steel mills. This distance is within the limit of influence known of some of the cloud seeding experiments reported, which was beyond 200 km (Brier *et al.* 1967 and Neyman *et al.* 1969).

2. Location of steel mills and selection of raingauge stations for the study

The managing agency of the Indian Iron and Steel Company Ltd., located at Burnpur, passed into the hands of Martin & Co. in the year 1892 and the company then began to expand and develop into the organisation as it exists today. The Tata Iron and Steel Company came into existence at Jamshedpur in 1907. There was no other steel industry in the region until as recently as 1959 when the Hindustan Steel Ltd. started its first chain of the three steel mills in the country at Durgapur (23°29′N, 87°19′E), Rourkela (22°13′N, 84°53′E) and Bhilai (21°12′N, 88°25′E), in the states of West Bengal, Orissa and Madhya Pradesh respectively.

The selection of raingauge stations for the study in a situation as at present, where the effect of two steel mills located in separate but not far distant regions has to be taken into account simultaneously, poses some problem because the same station which is to be considred as the control (upwind station) with reference to one steel mill has to satisfy the requirement of control station with reference to the other steel mill too. The following criteria have, therefore, been observed in the selection of stations : (*a*) the stations chosen should be so located in the four quadrants with respect to the point midway between Burnpur and Jamshedpur (Jamshedpur is about 125 km southwest of Burnpur) that the particular station which lies in the upwind direction serves, with reference to the others, as the control for both the steel mills,(*b*)the stations are located as uniformly as possible with respect to the point midway between Burnpur and Jamshedpur, and (*c*) reliable rainfall data are available for the stations considered for a period of atleast 20 years before 1892. The four stations selected which satisfied these criteria are Berhampore (24°08′N, 88°16′E) in the northeast, Midnapore (22° 25′N, 87° 18′E) in the southeast, Chaibasa (22° 33′N, 85° 49′E) in the southwest and Hazaribagh (23° 59′N, 85° 22′E) in the northwest quadrants. The stations are situated at distances ranging from 100 to 200 km from the point midway between Burnpur and Jamshedpur and their locations are shown in Fig. 1.

3. Considerations of control period and control and target stations

Monthly rainfall data are available for the four stations referred to above from 1872. Data for only two months, namely, August and February, which are representative of the monsoon and winter periods, when precipitation processes in the cloud are considered to be different, have been taken into account in the present study. The data available for the period before 1892 (this period is designated in the present study as the pre-industrial period) are considered to from the control data for the subsequent pariod (the period after 1892 is designated as the industrial period) ending 1955 upto which the available rainfall data have been considered. Data relating to the number of rainy days in each month are available from 1875 and these data have also been considered for the two months under study. Analysis has been made separately for the two months.

It is regarded that the influence, if any, of the steel mills on rainfall may become detectable at the station situated in the downwind quadrant (target) with respect to that situated in the upwind quadrant (control) because the effluents released tend to move with the wind. The winds of Jamshedpur and Asansol (this station is very close to Burnpur) for 0000 and 1200 GMT as available upto 1·5 km (this height is considered roughly to correspond to the cloud base level) for the period 1951-1963 have, therefore, been examined in order to decide which of the quadrants serves, with respect to the steel mills complex, as the control

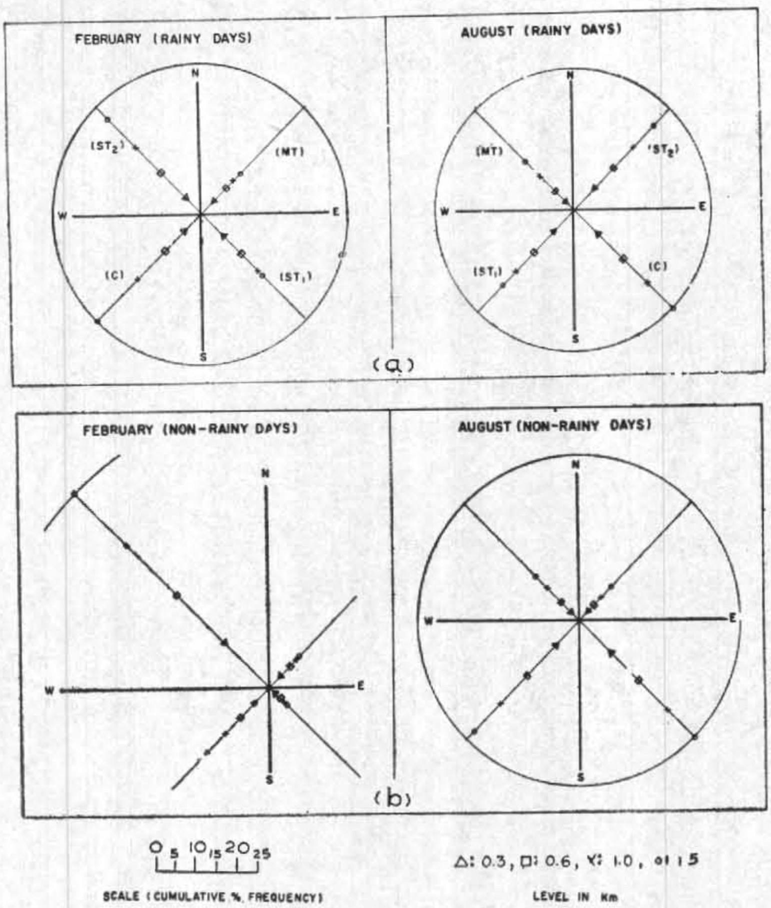

Fig. 2

Mean percentage frequencies of winds, quadrantwise, for 0·3, 0·6, 1·0 and 1·5 km levels given in a cumulative manner (a) for rainy days and (b) for non-rainy days

and which as the target. The analysis has been done stratifying the data into two categories, rainy days and non-rainy days. The 13-year period referred to above has been chosen because data for this period are readily available on punched cards. The mean percentage frequencies of winds in the four quadrants for 0·3, 0·6, 1·0 and 1·5 km have been given in a cumulative manner in Figs. 2 (a) and 2(b), for rainy days and non-rainy days respectively. The frequencies referred to are plotted on the lines bisecting the quadrants.

The winds on rainy days (Fig. 2a), which only have been considered in the present study, are not the same as those on non-rainy days (Fig. 2b) in both February and August. From Fig. 2(a) it is seen that the winds extend into all the four quadrants suggesting that no quadrant can be uniquely considered for the purpose of either control or target. The next alternative left, therfore, has been to consider the quadrant of maximum cumulative frequency as control and the remaining quadrant as targets (mean target and subsidiary targets in the manner to be explained) and this is what has been done. In the month of Feburary, the southwest quadrant, which is associated with maximum cumulative frequency becomes the control. The opposite quadrant, northeast, becomes the main target (MT). Of the two remaining quadrants, the northwest is associaed with the next maximum cumulative frequency. The opposite quadrant, which is southeast is designated as the first subsidiary target (ST_1) and the other quadrant being designated as the second subsidiary target (ST_2). The quadrants have been classified, on similar lines, in the month of August also. Stated stationwise, the classificatin made is as shown in Table 1.

4. Correlation of rainfall of control station with that of target station

The control and target stations, to be chosen for this study as on similar lines in conventional cloud seeding experiment, should satisfy one important criterion, namely, the rainfall value of the two stations during the pre-industrial period should show a high correlation, so that the amount of rain which would have fallen at the target station in the absence of the industry can be estimated **from**

TABLE 1

Control-target classification of stations according to month

Month	Control (C)	Main Target (MT)	Subsidiary Target	
			ST_1	ST_2
Feb	Chaibasa	Berhampore	Midnapore	Hazaribagh
Aug	Midnapore	Hazaribagh	Chaibasa	Berhampore

TABLE 2

Correlation coefficient between monthly rainfalls of control station and other stations

Target	Period				
	1872-1892	1893-1913	1914-1934	1935-1955	1893-1955
February (Control: Chaibasa)					
Berhampore (MT)	0·53	0·85 (0·03)	0·64 (0·30)	0·68 (0·24)	0·68 (0·18)
Midnapore (ST_1)	0·50	0·92 (<0·01)	0·72 (0·14)	0·75 (0·10)	0·82 (0·01)
Hazaribagh (ST_2)	0·84	0·74 (0·20)	0·76 (0·24)	0·67 (0·11)	0·73 (0·13)
Total target	0·75	0·93 (0·03)	0·84 (0·24)	0·77 (0·44)	0·86 (0·14)
August (Control: Midnapore)					
Hazaribagh (MT)	0·37	0·34 (0·46)	—0·23 (0·03)	0·22 (0·31)	0·11 (0·15)
Chaibasa (ST_1)	0·60	0·55 (0·42)	0·48 (0·31)	0·25 (0·09)	0·41 (0·16)
Berhampore (ST_2)	0·24	0·10 (0·32)	0·23 (0·50)	0·15 (0·40)	0·17 (0·40)
Total target	0·63	0·54 (0·35)	0·27 (0·08)	0·32 (0·12)	0·37 (0·10)

Figures in brackets show the levels of significance of the difference in correlation between the given period and the control period for one-tailed test

the rain which fell at the control station after the commencement of the industry. The correlation coefficient found of monthly rainfall of the control station with that of each of the target stations for the pre-industrial period is given in Table 2. The values obtained in the case of the main target stations are small, *i.e.*, 0·53 in February and 0·37 in August. However, the control station rainfall is seen to be correlated better with the rainfall of one of the subsidiary target stations, namely, Hazaribagh in February and Chaibasa in August (*vide* figures under column 2 of Table 2). The low values of the correlation noticed between rainfall of the control and the target stations, as considered, therefore, constitute a drawback in the present study.

5. Analysis

The monthly rainfall data have been grouped, for the February and August months separately, for each successive 21-year period commencing from 1872. The 21-year period considered is arbitrary. The data have been treated as follows: (1) by preparing double mass curves and estimating, from the slope changes noticed in them, departures in rainfall at the target stations during the different time periods after 1892, (2) by considering the mean rainfall values for different time periods from the basic monthly rainfall data and estimating on the basis of the control data, departures in rainfall at the target stations during the different time periods after 1892, and (3) by calculating the rank correlations of target-to-control rainfall ratio values with the time and examining from the values so obtained whether significant variations have taken place in the trends of the rainfall ratios after 1892.

(*i*) *Double mass curves*

The double mass analysis, which is based on slope changes of the double mass curves, is conventionally used for identifying or adjusting inconsistencies arising out of the non-representative factors such as change in location or exposure changes in the rainfall record of a station, by comparing its time trend with that of other adjacent stations. But, in the present study, this method has been used for estimating the departures in rainfall at each target station by comparing its time trend with that of the control station. The assumption tacitly made for this purpose, although questionable, has been that the changes noticed in the slopes of the double mass curves are entirely due to changes caused in the rainfall trends. The assumption is partly justified because it is noticed from the station history sheets available that, of the four stations considered in the study, the location of one of the raingauge stations, namely, Midnapore, has not changed since its first installation and that the locations of the other three stations have undergone only minor changes. Analysis by double mass curves is also a technique which is sometimes used for evaluation of weather modification experiments (Dessens *et al.* 1970).

Double mass curves have been prepared (*vide* Kohler 1948) for the three target stations with respect to the control station for February and August separately and given in Figs. 3 and 4 respectively. The points corresponding to the

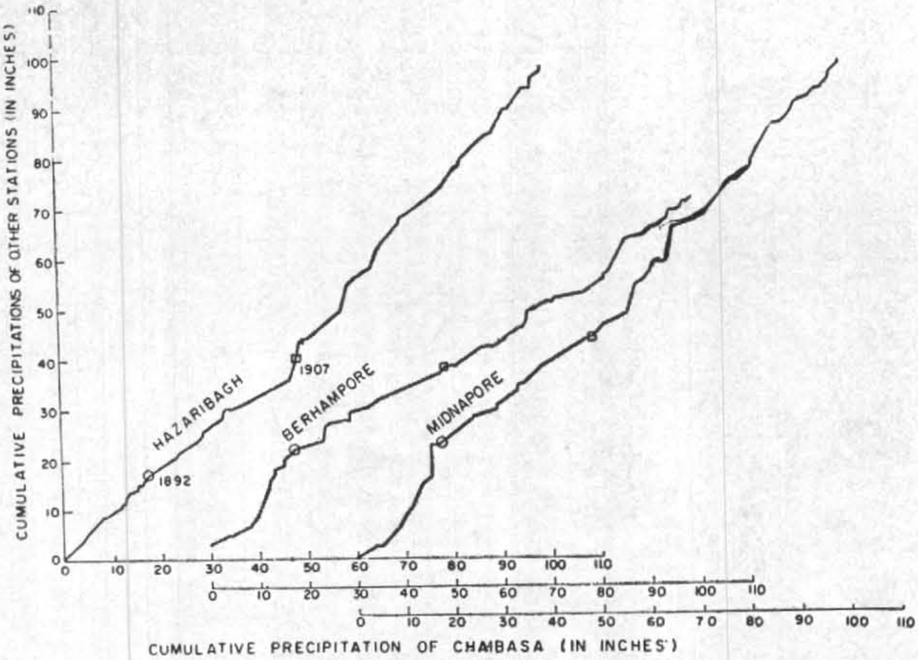

Fig. 3

Double mass curves showing cumulated precipitation in inches, for February

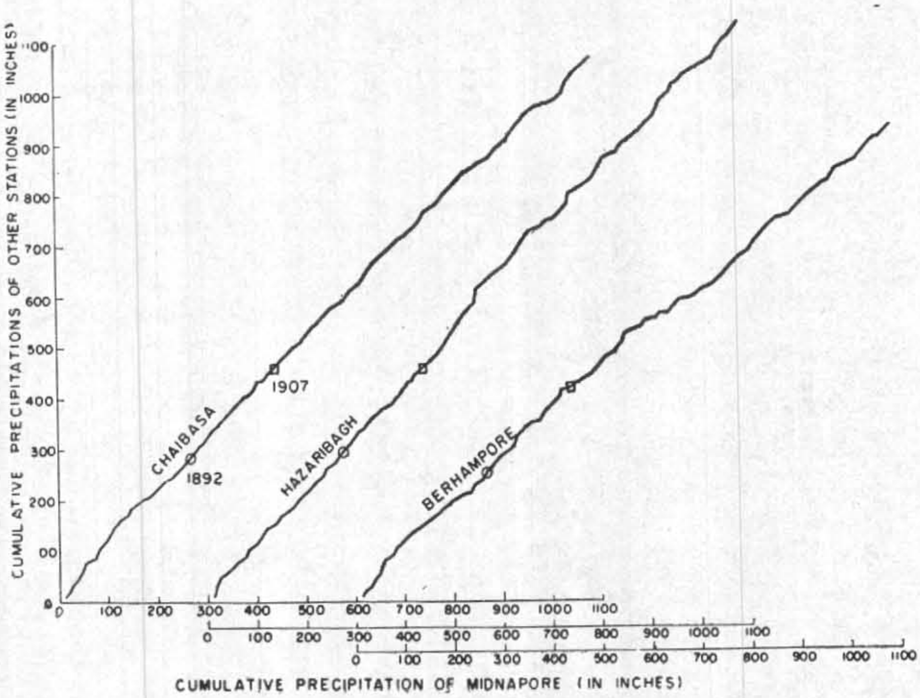

Fig. 4

Double mass curves showing cumulated precipitation in inches, for August

TABLE 3

Percentage departures in rainfull evaluated from slopes of double mass regressions

Target	Period 1893-1913	1914-1934	1935-1955	1893-1955
	February (control : Chaibasa)			
Berhampore (MT)	−63	−53	−37	−51
Midnapore (ST_1)	−48	−28	−31	−31
Hazaribagh (ST_2)	−6	21	23	15
Total Target	−43	−24	−20	−26
	August (control : Midnapore)			
Hazaribagh (MT)	6	−1	−1	6
Chaibasa (ST_1)	−3	−7	−16	−9
Berhampore (ST_2)	0	−27	−7	−10
Total Target	1	−11	−8	−4

TABLE 4

Period mean rainfall in inches

Target	Period 1872-1892	1893-1913	1914-1934	1935-1955	1893-1955
			February		
Chaibasa (C)	0·84 (1·03)	1·86 (2·34)	1·16 (1·47)	0·86 (0·80)	1·29 (1·71)
Berhampore (MT)	1·05 (1·26)	0·92 (1·19)	0·69 (0·62)	0·73 (1·26)	0·78 (1·07)
Midnapore (ST_1)	1·09 (1·44)	1·44 (1·97)	1·15 (1·69)	0·97 (1·18)	1·19 (1·66)
Hazaribagh (ST_2)	0·81 (0·91)	1·50 (1·54)	1·36 (1·53)	0·94 (0·77)	1·27 (1·35)
Total Target	0·98 (0·95)	1·29 (1·42)	1·07 (1·11)	0·88 (0·97)	1·08 (1·19)
			August		
Midnapore (C)	12·90 (6·29)	11·60 (3·51)	13·22 (4·50)	13·96 (5·01)	12·93 (4·49)
Hazaribagh (MT)	13·30 (4·22)	12·65 (4·22)	13·42 (5·26)	14·17 (4·91)	13·41 (4·86)
Chaibasa (ST_1)	13·25 (5·44)	12·25 (3·98)	12·33 (4·47)	12·50 (3·70)	12·36 (4·06)
Berhampore (ST_2)	11·86 (4·90)	10·81 (4·22)	9·39 (4·74)	12·15 (4·10)	10·78 (4·51)
Total target	12·80 (3·17)	11·90 (2·50)	11·71 (2·61)	12·94 (2·77)	12·18 (2·68)

Values of standard deviation are given in brackets

years 1872 and 1907, which have been referred to under 2, are shown in the figures.

The cruves for the industrial period of February showed larger deviations than those of August from the corresponding curves for the pre-industrial period. Also, it is noticed that the curves relating to Berhampore, which is the main target station in February, showed the largest deviation. For no station and for no time period the double mass curve obtained was a straight line, possibly due to the poor correlations of rainfall referred to earlier.

Based on the equations obtained for the best fit straight lines, the percentage departures in rainfall during the three industrial periods from that of the pre-industrial period have been calculated for the different stations and given in Table 3. Negative departures have been mostly noticed both in February and in August. These departures ranged upto 63 per cent in February (as in the case of the main target) and upto 27 per cent in August (as in the case of the second subsidiary target). Considering the entire industrial period as one single period, and the three target stations as one single target, it is seen that the departures continue to remain negative, being 26 per cent in February and 4 per cent in August.

(*ii*) *Period mean rainfall*

The values obtained of the mean rainfall for February and for August during the successive 21-year periods are given in Table 4. Also, the values of the ratio of mean rainfall at each target station to that at the control station are given in Table 5. The percentage variation in rainfall suggested during the industrial periods is given by figures in brackets in Table 5. The following features noticed are of interest.

February — The total amount of rainfall received in the month was small, *i.e.*, about 1 inch, and it fluctuated widely from year to year (*vide* the values of standard deviation in Table 4 which are found invariably larger than the period means). The rainfall in industrial periods at three stations, one of which is control, recorded increase, sometimes even exceeding 100 per cent, as compared to the rainfall in pre-industrial period (*vide* Table 4). However, considering the ratio of rainfall received at each target station with that at the control station (*vide* Table 5), it is noticed that the mean rainfall at the target stations, with respect to the control station, showed more often a decrease in the industrial period as compared to what it was in the pre-industrial period (*vide* figures in brackets of

TABLE 5

Ratio of period mean rainfall of each target station to that of the control

Target	Period				
	1872-1892	1893-1913	1914-1934	1935-1955	1893-1955
February (control : Chaibasa)					
Berhampore (MT)	1·25	0·50 (—60)	0·60 (—52)	0·85 (—32)	0·60 (—52)
Midnapore (ST_1)	1·30	0·78 (—40)	1·00 (—24)	1·12 (—14)	0·92 (—29)
Hazaribagh (ST_2)	0·96	0·81 (—16)	1·18 (+23)	1·10 (+14)	0·98 (+3)
Total target	1·17	0·69 (—41)	0·92 (—21)	1·02 (—13)	0·83 (—29)
August (control : Midnapore)					
Hazaribagh (MT)	1·03	1·09 (+6)	1·01 (—2)	1·02 (—2)	1·04 (+1)
Chaibasa (ST_1)	1·03	1·06 (+3)	0·93 (—9)	0·90 (—13)	0·96 (—7)
Berhampore (ST_2)	0·92	0·93 (+1)	0·71 (—23)	0·87 (—5)	0·83 (—9)
Total target	0·99	1·03 (+3)	0·89 (—11)	0·93 (—7)	0·94 (—5)

Suggested percentage changes in rainfall in the industrial periods are given in brackets

Table 5). The decrease noticed ranged, in the case of the main target station, upto 60 per cent.

August — The relative variation noticed in rainfall from one period to another at different stations during this month is much less than what it was during the corresponding period in the February month (compare figures of February and August in Table 4). Considering the ratios of rainfall at each target station with that at the control station it is seen that in the later two of the three industrial periods the mean rainfall at all the target stations, with respect to the control station, showed only a decrease (*vide* Table 5).

(*iii*) *Application of statistical tests on ratio values*

The individual monthly ratio values obtained period-wise of the target-to-control rainfall have been subjected to (1) Cramer's test (parametric) for comparison of means of sub-periods with the mean of the whole period (Cramer 1946), (2) Student's t-test (parametric) for the difference between the two means (Fisher 1925), (3) median (non-parametric) and (4) Mann-Whitney (non-parametric) tests for difference in location (Mann and Whitney 1947). The results of tests of (1) and (2) are given in Table 6 and of (3) and (4) in Table 7. A summary of the tests which showed statistical significance at 10 per cent level is given in Table 8.

In the month of February, the main and the first subsidiary targets showed statistically significant departures. But, in August, it is only the second subsidiary target which showed such departures. In both the months these departures, as have already been pointed out, are negative.

(*iv*) *Trends in rainfall*

Spearman's rank correlation ceofficients, with time, of the February and August rainfall have been calculated (Woodcock and Jones 1970). Such coefficients, with time, have been also calculated of the target-to-control rainfall ratios. The levels of significance of the t-statistic evaluated from the rank correlation coefficients, are given in Tables 9 and 10.

The rainfall patterns, during February of all the stations have indicated statistically significant negative trend in the latest 21-year industrial period considered, namely, 1935—1955. The rainfall patterns during August of all the stations also indicated negative trend during the same period, but it is significant only at the main target station. However, the target-to-control rainfall ratios both during February and August have, in general, not shown significant trends either in the pre-industrial or in the industrial periods.

(*vi*) *Progressive variation in correlation between rainfalls of the target and control stations*

As already mentioned, the rainfall at the control station was found poorly correlated with that of the target station in the pre-industrial period. However, if there are systematic changes taking place in the rainfall of one of or both the stations in the industrial period, the feature may be reflected by a different value of the correlation coefficient of the target-control rainfall in the industrial period as compared to what it was in the pre-industrial period. With a view to examining this feature, the values of correlation coefficient of rainfall of the control station, with that of each of the target stations have been evaluated, for the three successive industrial periods considered. The values, which are given in Table 2, point out that, in February, the correlation coefficients for the main target station and one of the subsidiary target stations have considerably improved in the industrial period. But, in August, the values have deteriorated at all the stations. Some of the variations noticed in the correlation have been statistically significant at 10 per cent level (*vide* figures in brackets in Table 2). If improvement in correlation is

TABLE 6

Levels of significance from Cramer's test (one-tailed) and from student's *t*- test (one-tailed)

Target	Cramer's test				Student's *t*-test			
	1893-1913	1914-1934	1935-1955	1893-1955	1893-1913	1914-1934	1935-1955	1893-1955
				February (control : Chaibasa)				
Berhampore (MT)	0·37 (+)	0·32 (+)	0·18 (–)	0·40 (—)	>0·45 (+)	>0·45 (+)	0·03 (–)	0·40 (—)
Midnapore (ST_1)	0·20 (–)	0·12 (—)	>0·45 (–)	0·02 (—)	0·08 (—)	0·05 (—)	0·14 (—)	0·02 (–)
Hazaribagh (ST_2)	0·32 (+)	>0·45 (–)	0·18 (–)	0·30 (–)	>0·45 (–)	0·32 (–)	0·21 (—)	0·30 (—)
Total target	>0·45 (—)	>0·45 (–)	0·16 (–)	0·16 (–)	0·32 (–)	0·27 (–)	0·05 (–)	0·16 (–)
				August (control : Midnapore)				
Hazaribagh (MT)	>0·45 (–)	0·44 (+)	0·30 (–)	0·31 (—)	0·35 (–)	0·44 (—)	0·25 (—)	0·31 (—)
Chaibasa (ST_1)	0·25 (+)	0·25 (—)	0·17 (—)	0·17 (—)	0·44 (—)	0·20 (—)	0·12 (—)	0·17 (—)
Berhampore (ST_2)	0·31 (+)	0·03 (—)	0·44 (–)	0·07 (–)	0·30 (—)	0·04 (—)	0·17 (—)	0·07 (–)
Total target	0·35 (+)	0·16 (–)	0·25 (–)	0·10 (–)	0·30 (—)	0·12 (–)	0·11 (–)	0·10 (—)

TABLE 7

Levels of significance from the median test (two-tailed) and from Mann-Whitney test (one-tailed)

Target	Median test				Mann—Whitney test			
	1893-1913	1914-1934	1935-1955	1893-1955	1893-1913	1914-1934	1935-1955	1893-1955
				February (control : Chaibasa)				
Berhampore (MT)	0·10	0·04*	0·50	0·10*	0·02 (–)	0·01 (–)	0·06 (–)	0·01 (–)
Midnapore (ST_1)	0·20	0·30	0·80	0·50	0·04 (–)	0·08 (–)	0·28 (–)	0·07 (–)
Hazaribagh (ST_2)	0·30	0·99	0·80	0·99	0·39 (–)	0·27 (+)	0·41 (+)	0·41 (+)
Total target	0·30	0·99	0·70	0·99	0·04 (–)	0·25 (–)	0·24 (–)	0·10 (–)
				August (control : Midnapore)				
Hazaribagh (MT)	0·70	0·70	0·70	0·50	0·42 (–)	0·32 (–)	0·46 (–)	0·35 (—)
Chaibasa (ST_1)	0·99	0·70	0·70	0·99	0·42 (+)	0·22 (—)	0·19 (–)	0·27 (–)
Berhampore (ST_2)	0·99	0·70	0·99	0·80	0·38 (–)	0·03 (–)	0·43 (–)	0·17 (–)
Total target	0·99	0·20	0·70	0·50	0·40 (–)	0·09 (—)	0·22 (–)	0·17 (—)

Under the median test, the significance level is higher than the given value, except for the values marked by *

TABLE 8

Summary of tests in Tables 6 and 7

Target	1893–1913				1914-1934				1935-1955				1893-1955			
	Cr	St	MW	Med	Cr	St	MW	Med	Cr	St	MW	Med	Cr	St	MW	Med
							February (control : Chaibasa)									
Berhampore (MT)	—	—	*	—	—	—	*	*	—	*	*	—	—	—	*	*
Midnapore (ST_1)	—	*	*	—	—	*	*	—	—	—	—	—	*	*	*	—
Hazaribagh (ST_2)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total target	—	—	*	—	—	—	—	—	—	—	—	—	—	—	*	—
							August (control : Midnapore)									
Hazaribagh (MT)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Chaibasa (ST_1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Berhampore (ST_2)	—	—	—	—	*	*	*	—	—	—	—	—	*	*	—	—
Total target	—	—	—	—	—	—	*	—	—	—	—	—	*	*	—	—

Significant location is shown by star (*) and the other by dash (—)

Cr : Cramer's St : Student's MW : Mann-Whitney Med : Median

TABLE 9

Levels of significance from t-test for Spearman's rank correlation coefficients between rainfall and time (one-tailed)

Target	Period				
	1872-1892	1893-1913	1914-1934	1935-1955	1893-1955
			February		
Chaibasa (C)	0·35(–)	>0·45(+)	0·30(+)	<0·01(–)	0·20(–)
Berhampore (MT)	0·25(–)	0·30(—)	0·09(+)	0·10(—)	0·32(—)
Midnapore (ST_1)	>0·45(+)	0·30(+)	0·12(+)	0·02(–)	>0·45(—)
Hazaribagh (ST_2)	0·21(—)	>0·45(+)	>0·45(—)	0·02(—)	0·25(—)
Total target	0·30(—)	0·25(+)	0·18(+)	<0·01(—)	0·25(—)
			August		
Midnapore (C)	0·35(+)	>0·45(+)	0·15(+)	0·21(—)	0·06(+)
Hazaribagh (MT)	>0·45(—)	0·12(+)	0·22(—)	0·10(—)	0·25(+)
Chaibasa (ST_1)	0·30(—)	0·45(+)	0·10(+)	0·30(–)	0·37(+)
Berhampore (ST_2)	0·40(–)	0·32(–)	0·40(+)	0·15(–)	0·22(+)
Total target	0·15(—)	>0·45(–)	0·30(+)	0·09(—)	0·22(+)

to be considered as an indication of the presence of an additional agency which is affecting the rainfall of both the stations and that deterioration is an indication that the additional agency considered is affecting the rainfall of only one of the stations, the findings as above suggest that whereas the influence, if any,of the steel mills on rainfall, has been mainly restricted to the target stations during August, it is extending to the control station also during February.

Further, examination of Table 2 points out that the coefficients found have been invariably higher in February than in August. The feature shown suggests that the weather systems affecting the region in winter could be either larger in scale or more homogeneous in nature or both than in monsoon.

(vii) Number of rainy days

The results of analysis presented in Tables 3 and 5 suggested that rainfall at the target stations, with respect to the control, decreased during the industrial period. The question which naturally arises in this regard is whether the

TABLE 10

Levels of significance from t-test for Spearman's rank correlation coefficients between target-to-control rainfall ratios and time (one-tailed)

Target	Period				
	1872—1892	1893 –1913	1914 –1934	1935 –1955	1893 –1955
			February (control : Chaibaa)		
Berhampore (MT)	0·30(+)	0·20(—)	0·20(—)	0·15(+)	0·10(+)
Midnapore (ST_1)	0·15(+)	0·10(+)	0·30(+)	0·40(+)	0·10(+)*
Hazaribagh (ST_2)	0·35(—)	0·15(—)	0·40(—)	0·15(+)	0·25(+)
Total target	0·25(+)	0·40(+)	0·35(—)	0·20(+)	0·10(+)
			August (control : Midnapore)		
Hazaribagh (MT)	0·40(—)	0·20(+)	0·30(—)	0·45(+)	0·40(—)
Chaibasa (ST_1)	0·05(—)*	0·35(—)	0·30(+)	0·40(+)	0·10(—)
Berhampore (ST_2)	0·25(—)	0·25(—)	0·40(—)	0·35(—)	0·30(—)
Total target	0·15(—)	0·25(+)	0·30(—)	0·40(+)	0·35(—)

The levels are higher than actually indicated in all cases except those marked by *. In the cases marked by *, the levels are actually lower

TABLE 11

Ratio values of the number of rainy days at the target with the number at the control

Target	1875 –1892	1893 –1913	1914 –1934	1935 –1955	1893 –1955
			February (control : Chaibasa)		
Berhampore (MT)	1·06 (1·18)	0·71 (0·70)	0·80 (0·75)	0·58 (1·47)	0·69 (0·87)
Midnapore (ST_1)	1·00 (1·30)	0·80 (0·98)	0·90 (1·11)	0·85 (1·32)	0·85 (1·08)
Hazaribagh (ST_2)	1·17 (0·82)	1·00 (0·81)	1·05 (1·12)	1·00 (1·10)	1·01 (0·97)
Total target	1·08 (1·08)	0·84 (0·82)	0·92 (1·00)	0·81 (1·26)	0·85 (0·98)
			August (control : Midnapore)		
Hazaribagh (MT)	1·14 (0·90)	1·06 (1·03)	1·01 (1·00)	1·10 (0·93)	1·06 (0·98)
Chaibasa (ST_1)	1·05 (0·98)	1·01 (1·05)	0·98 (0·95)	1·00 (0·90)	1·00 (0·96)
Berhampore (ST_2)	0·95 (0·97)	1·04 (0·89)	0·97 (0·73)	0·97 (0·90)	0·99 (0·84)
Total target	0·96 (1·03)	1·04 (0·99)	0·98 (0·91)	1·02 (0·91)	1·01 (0·93)

Corresponding ratio values of rainfall per rainy day are given in brackets decrease in rainfall indicated has been brought about by the lessening of the number of rainy days or by the lessening of the rain activity per rainy day or by both. This aspect has been examined as follows. The ratio values of the number of rainy days at each target station to the number at the control station, as well as the ratio values of rainfall per rainy day are given in Table 11.

Examination of the figures in the table suggests that the ratio values of the rainy days and also the ratio values of the rainfall per rainy day largely decreased during the industrial period.

6. Discussion

(*i*) *February versus August rainfall*

The results of analysis from (*i*) double mass curves, (2) ratios of mean total rainfall (Table 5) and (3) ratios of mean rainfall per rainy day (Table 11) indicated that, after the establishment of steel industry in the states of West Bengal and Bihar, changes in rainfall had taken place in that region both in the months of February and August. The changes indicated in February have been more marked. Application of the parametric tests (these are valid best in the case of normal distribution) pointed out that only a few of the changes indicated have been significant. Of the two non-parametric tests applied (these tests are valid independent of the type of distribution) the more powerful one, which is the Mann-Whitney (Neyman and Scott 1967), pointed out that it is the February rainfall which showed significant changes (*vide* figures in the last column of Table 7). The features noticed, therefore, largely support the hypothesis that the steel mills complex has influenced the winter rainfall in the region.

(*ii*) *Possible cause for changes in February rainfall*

It is known from studies made at Delhi (28°35′N, 77°12′E) that the ice crystal process plays dominant role in the development of precipitation in the winter clouds in that region (Ramana Murty *et al.* 1960). The same feature may be considered to hold good in clouds in the Jamshedpur—Burnpur region also during the winter period in view of the fact that, when both the regions get rain in winter, it usually happens under the influence of the same passing western disturbances. The present finding, therefore, implies that the aerosols present in the effluents from the steel mills complex under question might be influencing the rainfall from clouds in that region by virtue of their ice-nucleating property. This inference appears to be consistent in that actual observations by Telford (1960) and by Langer (1968), as already stated, have shown that the effluents of steel mills could be prolific sources of ice-forming nuclei. The steel mills complex under question may be no exception.

(*iii*) *Rainfall in the more adjacent regions*

The problem which arises, however, is how to account for the suggested decrease of rainfall on the basis of the anticipated effects of the effluents (the effect of only aerosols is considered here whereas the effluents consist of aerosols, heat and water vapour) on the micro-structure-stability characteristics of clouds. This aspect is examined below. Ice-forming nuclei, which help develop precipitation more readily in winter clouds, by producing ice crystals at relatively warm temperatures, is only one type among the different types of aerosol to be present in the effluents. Giant size condensation nuclei (hygroscopic particles of radius one micron and above), which also help develop precipitation in both the monsoon and winter clouds, by providing comparatively few numbers of the very efficient precipitable size droplets, is another type. But, the large size condensation nuclei, specifically those present in the lower size end of the spectrum (large size condensation nuclei range from 0·1 to 1·0 micron in radius) and commonly known as the cloud condensation nuclei, which help inhibit rain development by increasing the number concentration of cloud droplets and thus reducing the average size of the droplets, is the other type. The net effect of the effluents on the cloud microstructure and thereby on its stability will, therefore, be dependent on the relative strength of each category of the aerosol present in the effluents and also on the prevailing cloud conditions in the region. If it is considered that the ice-forming nuclei as well as the giant size condensation nuclei present in the effluents have been affecting the winter clouds in the manner as anticipated of them, one should expect an increase in rainfall instead of the suggested decrease. A decrease in rainfall at 100 to 200 km distance from the steel mills may, however, be possible if a redistribution of precipitation has occurred on account of the clouds precipitating more than what is due from them in more adjacent regions. The same is also possible in case the inhibiting effect of rainfall by the cloud condensation nuclei in the effluents had been the most dominating influence in the entire region within 200 km from the steel mills. But, of the two alternatives cited, the first one, *i.e.*, precipitation increase in more adjacent regions, is what is considered more plausible because observations by Ogden (1969) have indicated that, except very close to the steel plant, the output of the ice-forming nuclei from the effluents makes a negligible addition to the back-ground at temperatures of meteorological importance. In that case, the output of the cloud condensation nuclei too from the effluents may not mean any significant addition to the back-ground at distances of 100 to 200 km from the sources. However, in the absence of any data on the aerosol state of the air in the steel mills region under question, no definite conclusion is possible. If the results reported in the literature of the heat island effect is any guide, the effect of the other effluents mentioned, namely, heat and water vapour, would not have extended beyond some tens of kilometres from the steel mills complex.

7. Conclusion

The results of the study, which are applicable to regions situated from 100 to 200 km from the Jamshedpur—Burnpur steel mills complex, have indicated that the steel mills complex could be responsible for the variations noticed in the February rainfall. The physical and chemical nature of the particulate effluents from the steel mills complex and their spatial distribution in and around the region within 200 km have to be known for identifying the causes of such variations.

Acknowledgement

The authors express their deep sense of gratitude to Shri K. N. Rao for the valuable suggestions received on the techniques of analysis used in the study.

REFERENCES

Changnon, S. A., Jr. 1968 *Bull. Am. Met. Soc.*, **49**, pp. 4-11.

Cramer, H. 1946 *Mathematical methods in Statistics*, Princeton Univ. Press, 575 pp., Princeton, N.J.

Dessens, H., Dessens, J. *et* J.P. la Caux 1970 *J. Rech. Atmos.*, **IV**, pp. 71-74.

Fisher, R. A. 1925 *Metron*, **5**, 3, p. 90.

Glenn W. Brier, Thomas H. Carpenter, and Dwight B. Kline 1967 Proc. fifth Berkeley Symp. on Math. Statistics and Probability, Vol. 5, Univ. California Press, Berkeley and Los Angles, pp. 209-221.

Hobbs, P. V., Radke, L. F. and Shumway, S. E. 1970(a) *J. Atmos. Sci.*, **27**, pp. 81-89.

1970(b) *Ibid.*, **27**, pp. 1216-1217.

Holzman, B. G. and Thom, H. C. S. 1970 *Bull. Am. Met. Soc.*, **51**, pp. 335-342.

Kohler, Max. A 1948 *Ibid.*, **30**, pp. 188-189.

Koteswaram, P. and Alvi, S. M. A. 1969 *Curr. Sci.*, **38**, 10, pp. 229-254.

Langer, G. 1968 Proc. First Nat. Conf. Weath. Modification, Albany, New York, pp. 220-227.

Mann, H. B. and Whitney, D. R. 1947 *Annals of Mathematical Statistics*, **18**, pp. 50-60.

Neyman, J. and Scott, E. L. 1967 Proc. fifth Berkeley Symp. on Math. Statistics and Probability, Vol. 5, Weather Modification Experiments, Univ. California Press, Berkeley and Los Angels, pp. 293-326.

Neyman, J., Scott, E. L. and Smith, J. A. 1969 *Science*, **163**, pp. 1445-1448.

Ogden, T. L. 1969 *J. Appl. Met.*, **8**, pp. 585-591.

Pramanik, S. K. and Jagannathan, P. 1953 *Indian, J. Met. Geophys.*, **4**, 4, pp. 291-309.

Ramana Murty, Bh. V., Biswas, K. R. and Ghosh Dastidar, B. K. 1960 *Ibid.*, **11**, 4, pp. 331-346.

Rao, K. N. and Jagannathan, P. 1963 Proc. of the UNESCO/WMO Symp. on "Changes of Climate", Rome, pp. 49-66.

Telford, J. W. 1960 *J. Met.*, **17**, pp. 676-679.

Woodcock, A. H. and Richard H. Jones 1970 *J. Appl. Met.*, **9**, pp. 690-696.