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Result of operational cloud seeding experiment over Rihand catchment in northeast India

R. K. KAPOOR, K. KRISHNA, U. S. DE,* K. G. S. NAIR,*
I. C. TALWAR*, S. K. SHARMA and
BH. V. RAMANA MURTY

Indian Institute of Tropical Meteorology, Poona

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ABSTRACT. A cloud seeding experiment, on operational basis, was undertaken during August-September, 1973 over the catchment area of the Rihand reservoir in the state of Uttar Pradesh. While the intended seeding operation was done on many days, the same could not be accomplished, for unavoidable reasons, on a number of days during the above period. Considering the latter category of days as control days and the areas adjoining the catchment as control areas, the result of the experiment was evaluated. The analysis suggested rainfall increase in the catchment area, due to seeding, by over 17 per cent. The increase, however, is statistically not significant.

1. Introduction

The results of cloud seeding experiments, either completed or in progress in India, have appeared (Roy *et al.* 1961, 1964; Biswas *et al.* 1967; Ramana Murty and Biswas 1968; Chatterjee *et al.* 1969, Kapoor *et al.* 1973 ; Krishna *et al.* 1974). But, none of the experiments reported was operational in nature. A unique experiment of the kind was conducted for the first time in northeast India in 1973.

An acute shortage of power developed in the state of Uttar Pradesh by July, 1973 due to low level of water in the Rihand reservoir. At the request of the State Government, an aerial cloud seeding experiment, was undertaken in the catchment area of the reservoir. The technique used for the purpose was salt particle seeding. The experiment commenced on August 5, 1973, one month after the receipt of the request, during which period all physical arrangements like chartering of suitable aircraft with necessary modificatons incorporated, procurement of seeding material, establishment of radiosonde station at the base of operations, planning for issue and receipt of weather orecasts and current weather data were completed. As the experiment was operational in nature, seeding was done on all the seedable days when flying became possible. The experiment came to a close on September 30, 1973 when the seeder aircraft returned from the base of operations.

At the time of commencement of the experiment and also in course of it, it was viewed that it would not be possible to make assessment of the result owing to the fact that the experiment conducted was without controls and it was operational in nature. However, in course of stock-taking of the situation after the completion of the experiment, it was realised that the seeding operation intended on every seedable day had not been conducted on a number of seedable days due to one or more of the following reasons: (*i*) late arrival of aircraft fuel, (*ii*) encountering of navigational difficulty, (*iii*) non-availability of aircraft due to over-hauling, and (*iv*) failure of ground transport arrangement due to reasons beyond control. As many as 27 seedable days were left unseeded during the 61-day period, August to September, 1973. Subsequently, it became possible to collect daily rainfall data not only for a few stations in the catchment area but also for some stations in the adjoining areas outside the catchment, for the above period. An attempt was, therefore, made to evaluate the result of the experiment on the basis that the days left unseeded could be considered as control days and the adjoining areas outside the catchment as control areas. The details of the

*India Meteorological Department

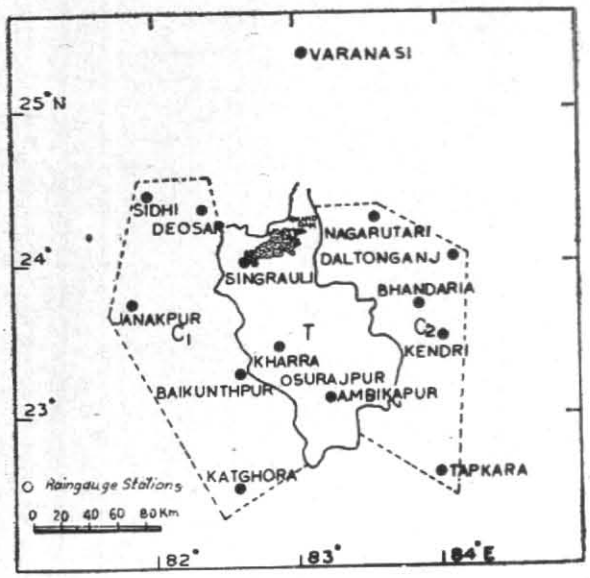

Fig. 1
Locations of target area, T, and control areas, C_1 and C_2. T is the Rihand catchment and the reservoir is shown stippled

experiment conducted and the result obtained are presented below.

It may be noted that rarely the results of operational experiments are evaluated. A notable exception in this regard was the one reported for the Florida region in U.S.A. (Simpson *et al.* 1972).

2. Experimental area

(*a*) *Target area*

The entire catchment covering an area of about 13000 sq. kilometres was the target (*vide* Fig 1). Most of the catchment is situated in the state of Madhya Pradesh. Its height, above mean sea level, ranges from 300 to 900 m with isolated peaks above 900 m. The reservoir, which is about 470 sq. km, is situated near the southern border of the state of Uttar Pradesh. Daily data for the two months' period, August to September, 1973, were available for four raingauge stations in this area.

(*b*) *Control area*

Two regions each covering about the same area as the catchment and adjoining its eastern and western boundaries were considered as two independent control areas. These are designated as C_1 (left control) and C_2 (right control). Daily rainfall data for the above two months' period were available for 5 stations in one area and for 6 stations in the other area. However, as data were available for only 4 stations in the target area, consideration of data for control areas was restricted to 5 raingauge stations.

3. Seedable day

If three out of the four following criteria are satisfied, the day was considered as seedable.

(*i*) The area forecast issued for the catchment should point out development of 3 octa or more of cumulus clouds.

(*ii*) The upper winds from 1 km to 3 km should be nearly steady. They may be all either easterly (046° to 135°) or southerly (136° to 225°) or westerly (226° to 315°) or northerly (316° to 045°).

(*iii*) The morning tephigram for the station Varanasi, which is the base of the operation, should indicte dew point depression not exceeding 5° at 700 mb and below.

(*iv*) Current weather report for Ambikapur, a station inside the catchment, should show presence of low cloud over the region.

Every day during August to September 1973, which was the period of operation, became a seedable day, according to the above consideration. But, as already mentioned, a number of days had to be left unseeded.

4. Seeding material

The material used for seeding, as in the experiments reported for other regions in India, consisted of common salt and soapstone taken in the ratio 10 : 1 and ground to a fine mixture with mode particle diameter of about 10 microns.

5. Aircraft and seed dispensing gadget

A Dakota aircraft, DC-3, fitted with a specially designed salt dispensing gadget (*vide* Krishna *et al.* 1974), and chartered from M/s. Airwcrks India Bombay, was made use of for the seeding operation. The seeding material was dispersed at the rate of 12 to 15 kg per 3 km of flight path. The amount of material seeded varied from 475 kg to 1875 kg per day.

6. Base of operation

The seeder aircraft was stationed at Babatpur aerodrome, Varanasi, which is about 100 km north from the northern border of the catchment. The seeding operation, in each flight, commenced when the aircraft entered the catchment.

7. Flight path and flight duration

The flight path followed for seeding was always inside the catchment. The route flown was dependent upon the wind at and above the level of seeding. If the wind was westerly (226° to 315°), the route flown was along and inside the

western border of the catchment. If it was easterly, (046° to 135°), it was along and inside the eastern border. If it was southerly, the route flown was restricted to the area from 15 kilometres interior of the eastern, western and northern borders, but extending upto the southern border. If the wind was northerly, it was restricted to the area from 15 kilometres interior of the eastern, western and southern borders but extending upto the northern border. If no clouds were present along the routes flown, as mentioned above, isolated clouds and/or cloud complexes, if any, inside the catchment were seeded and some of them more than once.

The total duration of flight generally ranged between 4 to 5 hours on a seeded day. The total flight path in clouds seeded ranged upto 480 kilometres.

8. Level of seeding

The material was released within clouds at levels ranging from few tens to few hundreds of metres above the cloud base. The seeding level, thus, varied generally between 1.5 km to 2.1 km above mean sea level. The amount of material released as well as the level at which it was released, on each day of seeding, are given in Table 1.

9. Visual observations

A careful watch was kept during each seeding flight, of the development of rain, if any, following seeding. The observations made for the purpose were visual and consisted in observing the splashing of raindrops on the observational windows as well as on the wind shield of the aircraft.

10. Analysis and results

Seeding was accomplished on a total number of 34 seedable days during the period August 5 to September 30, 1973.

(*i*) *Visual observations* — Visual observations made pointed out rain, following seeding, on all but 2 days, namely, September 17 and 18.

(*ii*) *All seedable days considered together* — The values evaluated of average rainfall in mm per station per day for the target area and the two control areas are given in Tables 2 for all the seeded and not-seeded days respectively. The values of total rainfall per station on seeded and not-seeded days for the target area and the two control areas are given in Table 3. The ratio value of rainfall of target area to that of each control area is given in the table. The value of the double ratio, *i.e.*, the ratio of the two values of ratio referred to above for seeded and not-seeded days, is also given in the table.

The departure of the double ratio from unity signifies the result of the experiment, positive departure signifying positive result and negative departure signifying negative result. The value of the double ratio was more than unity with respect to both the control areas. The feature suggests that seeding caused increase of rainfall in the target area. The departures noted from unity, were 0.286 and 0.173. These features suggest that rainfall in the catchment area increased by 28.6 per cent with reference to the left control and by 17.3 per cent with reference to the right control area.

The increases in rainfall referred to above are not statistically significant according to Mann-Whitney test.

(*iii*) *Seedable days considered windwise* — The distribution of seeded and not-seeded days, considered windwise, is presented in Table 4. Results were evaluated for all the four categories of winds separately in the manner as in (*ii*) and given in Table 5.

TABLE 1

Details of seeding

Date	Amount of material (kg)	Level of seeding amsl (km)	Path length seeded (km)
	August 1973		
5	800	1·7	400
7	1500	1·7	440
8	1500	1·7	615
9	1500	2·0	455
10	1500	1·8	480
16	1500	1·8	310
17	1400	1·9	385
20	1500	2·0	305
21	1500	1·6	400
22	1875	1·8	440
23	1575	1·8	480
24	1800	1·8	370
25	1875	1·8	450
27	1875	1·8	450
28	1875	2·0	340
29	1875	1·8	420
30	1875	1·9	370
31	1875	1·8	400
	September 1973		
1	1875	1·8	480
2	1875	1·7	385
4	800	1·5	175
5	1875	1·8	435
6	1875	1·7	385
7	1850	1·3	480
8	1875	1·7	450
9	1875	1·7	480
10	1875	1·5	480
11	475	1·4	160
15	1500	1·7	480
17	1000	1·7	240
18	1500	1·7	400
19	675	1·7	240
22	675	1·7	240
23	1200	2·6	355

TABLE 2

Average rainfall (mm) per station in target area T and control areas C_1 and C_2 on seeded and not-seeded days

Date 1973		Target T	Control C_1	Control C_2
		Seeded days		
August	5	0·25	0·66	2·00
	7	28·65	18·40	17·16
	8	15·88	5·52	6·88
	9	3·25	1·74	1·09
	10	0·00	5·98	13·32
	16	1·50	7·74	3·88
	17	23·10	30·50	16·68
	20	12·90	4·00	6·36
	21	10·10	2·80	2·34
	22	9·58	2·40	7·48
	23	3·75	14·12	0·60
	24	6·75	9·32	5·00
	25	9·05	7·70	7·50
	27	84·25	61·04	13·10
	28	23·08	11·74	1·90
	29	0·00	0·40	2·04
	30	0·00	0·00	7·12
	31	0·10	0·00	9·72
September	1	1·25	3·26	14·00
	2	60·70	40·68	17·32
	4	9·48	3·68	1·80
	5	1·50	1·90	0·66
	6	2·90	10·38	7·44
	7	23·85	3·04	7·26
	8	24·25	1·96	12·50
	9	0·25	0·70	10·56
	10	0·60	9·78	3·02
	11	15·75	25·72	11·40
	15	5·00	1·40	1·04
	17	0·05	2·38	5·00
	18	0·00	2·34	2·64
	19	3·78	0·60	14·08
	22	8·53	7·10	23·50
	23	10·88	15·60	55·18
		Not-seeded days		
August	1	4·50	7·44	10·90
	2	24·35	16·70	17·28
	3	0·20	18·98	1·40
	4	1·90	5·98	1·32
	6	1·30	4·20	8·84
	11	11·30	35.24	15·90
	12	14·80	35·70	15·56
	13	42·45	18·36	13·72
	14	1·78	0·70	8·00
	15	2·90	2·00	2·40
	18	20·30	10·76	47·76
	19	44·78	36·16	33·88
	26	1·53	16·24	16·36
September	3	33·53	27·50	25·36
	12	32·25	18·14	12·56
	13	3·25	11·60	1.24
	14	16·53	8·52	1·78
	16	13·00	5·48	4·98
	20	10·75	1·26	8·40
	21	15·18	5·24	9·92
	24	31·80	28·14	31·04
	25	13·30	10·48	21·56
	26	6·90	6·04	5·20
	27	0·50	0·00	0·40
	28	7·25	15.66	0·80
	29	1·35	13·88	8·84

The values of the double ratio given in the last two columns of Table 5 suggest that seeding caused increase of rainfall in the target area in six cases and decrease of rainfall in two.

(*iv*) *Level of reservoir* — The level of the reservoir was 798.40 ft on August 5, 1973 when the experiment commenced. It was 828.00 ft on September 30, 1973 when the experiment concluded. The daily consumption of the water level by the UPSEB was about 0.2 ft. Thus the period of seeding marked an effective rise of about 41 ft in the reservoir level. The respective levels on August 1 and September 30, in the three consecutive years 1971-73 are given in Table 6.

11. Discussion

The target area and the two control areas considered, cover as large as about 13000 sq. km each. The possibility of the released seeds in the target area substantially affecting either of the control areas is, therefore, ruled out. But the effect, if any, in this regard would only be to cause an underestimate of the result, as on not-seeded days no area was affected.

The control areas chosen are those adjoining the target area. As the target and control areas in any experiment should possess a high degree of rainfall correlation and as this condition is normally satisfied in the case of nearby areas, the choice made of the control areas in the present study is reasonable.

The dates on which the experiment could not be conducted were considered to be control days. As the reasons which precluded conduct of the experiment on such days were many and as all those days were seedable days, and also as the number of such days was of the same order as the number of seeded days, it is considered that the two series of seeded and not-seeded days in the present experiment are nearly as good as those selected for that purpose by randomization.

For the reasons, as stated above, the present experiment may be likened to the well-known single target-control randomization experiment.

Analysis of rainfall in the target area on the seeded and not-seeded days with respect to both the control areas, considered separately, pointed out change in rainfall, attributable to seeding, in the same direction. The result, which was an increase of rainfall appears to be, therefore, reassuring. Analysis made wind-wise, which pointed out increase of rainfall in 6 out of the 8 cases, lends further support to the above inference.

Also, the result (increase of rainfall) is consistent with what was anticipated on the basis of the findings from visual observations following seeding.

TABLE 3

Total rainfall (mm) per station in target area T and control areas C_1 and C_2 on seeded and not-seeded days and ratio values thereof

Seeded days (s)					Not-seeded days (ns)					Double ratio	
Target T	Control C_1	Control C_2	$\frac{T(s)}{C_1}$ (A)	$\frac{T(s)}{C_2}$ (C)	Target T	Control C_1	Control C_2	$\frac{T(ns)}{C_1}$ (B)	$\frac{T(ns)}{C_2}$ (D)	$\frac{A}{B}$	$\frac{C}{D}$
401·66	314·58	311·48	1·277	1·289	357·68	360·40	325·40	0·993	1·099	1·286	1·173

TABLE 4

Distribution of seeded and not-seeded days

Wind direction	Seeded	Not-seeded
Easterly (046°-135°)	8	3
Southerly (136°.225°)	9	6
Westerly (226°-315°)	7	14
Northerly (316°-445°)	7	3
Variable wind	3	—

TABLE 5

Total rainfall (mm) per station in target area T and control areas C_1 and C_2 on seeded and not-seeded days and ratio values thereof — windwise

Wind direction	Seeded days (s)					Not-seeded days (ns)					Double ratio	
	Target T	Control C_1	Control C_2	$\frac{T(s)}{C_1}$ (A)	$\frac{T(s)}{C_2}$ (C)	Target T	Control C_1	Control C_2	$\frac{T(ns)}{C_1}$ (B)	$\frac{T(ns)}{C_2}$ (D)	$\frac{A}{B}$	$\frac{C}{D}$
Easterly	119.83	81.90	56.28	1.463	2·129	70.71	42·66	52.20	1.659	1·355	0.882	1.571
Southerly	109.44	60.54	39.30	1·808	2.785	82.90	76.84	85.24	1.079	0·973	1.676	2·862
Westerly	55.55	53.30	66.54	1.042	0.835	148.71	186.40	98·48	0.798	1.510	1.306	0.553
Northerly	89.61	67.74	78.76	1.323	1.124	55.36	54.50	89.48	1.016	0.619	1.302	1.816

But, the consistency noted is also of a surprise, for, the data of rainfall used for analysis were 24-hour totals and the duration of the experiment conducted was barely a few hours per day.

The increase of rainfall suggested in the present experiment, is over 17 per cent. This value is in general agreement with the 21 per cent increase shown by the long series of experiments conducted in the Delhi-Agra-Jaipur region (Biswas *et al.* 1967) which also lies in the monsoon trough zone as the Rihand catchment.

12. Cost of experiment and benefit cost -ratio

A sum of Rupees 5.5 lakhs was estimated to have been spent on the experiment. Considering

TABLE 6

Level of reservoir (ft) on given dates

Date	1971	1972	1973*
Aug 1	865·20	839·91	797·95
Sep 30	878·98	863·20	828·00
Rise in level	13·78	23·29	30·05

*Seeding experiment conducted.

the total area covered by the experiment, the cost of seeding as evaluated was 17 paise per acre for 2 months.

If 10 per cent of the increase in the reservoir level is attributable to the effect of seeding (this is reasonable because the experiment suggested an increase in rainfall of 17.3 per cent with respect to the right control area and 28 6 per cent with respect to left control area), and if the cost of water is rupees ten per acre foot, at the mean level of operation, the benefit cost-ratio in the present experiment would be in the range 3 to 7 depending upon the shape of the reservoir.

13. Conclusion

A cloud seeding experiment, on operational basis, was conducted over the catchment area of Rihand reservoir during August-September, 1973. The result was evaluated based on certain considerations made with regard to control days and control areas. The analysis suggested that the rainfall in the catchment area during the period of seeding increased by over 17 per cent.

The facility of self recording raingauges and the facility of radar, either ground based or aircraft based, would improve the scientific value of the experiment.

Measurements of aerosol concentration and cloud drop size distribution were made over the catchment area during the period of seeding. The results of these measurements will be presented separately.

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