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Chemical Composition of Rain Water across the Western Ghats

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ABSTRACT. Analysis of rain water samples collected in the path of the monsoon air stream at three locations from the west coast suggested that clouds in the downwind of the Western Ghats are modified to continental type as a result of preferential depletion of certain particulate matters from the cloud air before crossing the crest and addition of certain other particulate matters of local origin after entry into the plateau. Based on the measurements, a method has been proposed for stimulating rain in clouds of the leeside of the Western Ghats.

1. Introduction

Study of the chemical constituents in rain water is of interest in cloud physics as some of the constituents play a potential role in rain formation in clouds. Measurements by Turner (1955) and by Spencer and Woodcock (1963) have indicated that the mechanism of raindrop growth in warm and supercooled clouds could be inferred from raindrop salinity with size. Investigations by Khemani and Ramana Murty (1968) using bulk rain water samples have suggested that there can be what is called a 'right type of chemical climate' for a region whch will help accelerate colloidal instability of clouds in the area.

It is well known that rainfall on the lee of a mountain is very different from what it is on the wind-ward side. The processes of precipitation are influenced not only by the dynamic and thermodynamic factors controlling convection and mixing in the atmosphere, but also by the physico-chemical properties of the particulate matter suspended in the air. Possible modification of convective storms by lee waves has been pointed out by Booker (1963). Also, the role played by orography in causing rainfall has been investigated by Sarker (1966 and 1967). However, the changes which take place in the chemical state of the air on the lee as compared to what it is on the wind-ward side and their possible effect on precipitation development in lee clouds have not been studied. Information in this regard would be of help in the consideration of weather modification experiments in lee clouds. A study, therefore, has been undertaken with this end in view on the chemical state of the air at three locations which have been conveniently chosen, with reference to the Western Ghats, in the path of the monsoon airstream. As the concentrations of chemical constituents in rain water are highly reflective of those in the air, the study entailed collection of rain water samples at the three locations and their subsequent analysis for the different chemical constituents. The results of measurements made are presented and discussed.

2. Collection of rain water and analysis

Rain water was collected at the coast (Santacruz, Bombay: 10° 07′N, 75 °51′E, 14 m a.m.s.l.), near the crest (Lonavla: 18° 45′N, 73° 24′E, 625 m a.m.s. l. and about 60 km from the coast) and in the plateau (Poona: 18° 32′N, 73° 51′E, 559 m a.m.s l. and 105 km from the coast). The orographic profiles from the coast at Bombay to plateau at Poona is as shown in Fig. 1. The height rises from west to east on the average to 0·8 km in a distance of 65 km and then ends in a plateau of average height 0·6 km. The normal monsoon rainfall (June—September) at the three places Bombay, Lonavla and Poona is 2489, 4114 and 503 mm respectively.

Rain water was collected using stainless steel funnels of 30 and 45 cm diameter into 1000 c.c. polythene bottles previously cleaned and rinsed with double distilled water. The duration of collection of rain sample was, on the average, a few hours though it had to be much less on a few occasions when rainfall was heavy. Samples were collected at Bombay, Lonavla and Poona on 9, 4 and 8 days respectively, some of them simultaneously, during the latter half of the monsoon month, July 1966. The chemical constituents analysed are chloride, sulphate, sodium, potassium and calcium. The anions were measured by Bausch and Lomb Colorimeter and the cations by Kipp and Zonen flame photometer using standard techniques.

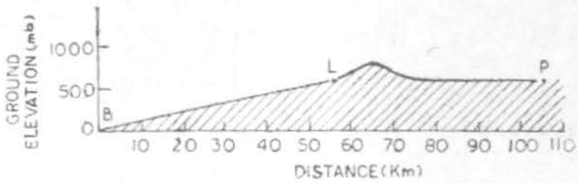

Fig. 1. Orographic profile of the rain collection sites

B—Bombay (Coast), L—Lonavla (Crest), P—Poona (Plateau)

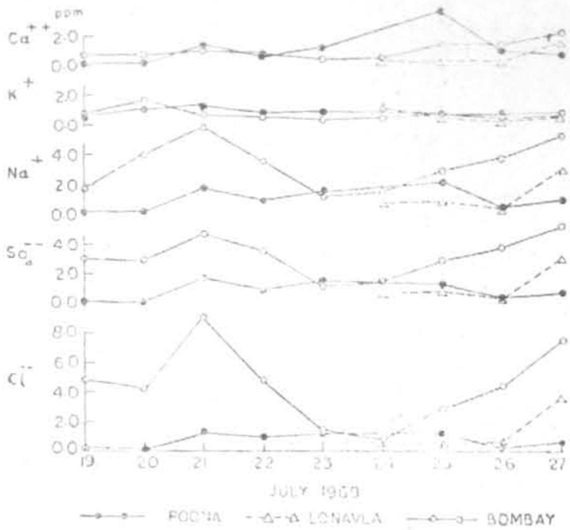

Fig. 2. Variation in the concentration of each chemical constituent in rain water at Bombay, Lonavla and Poona

3. Results and discussions

The concentratins of different chemical constituents in rain water are shown in Fig. 2 and the ionic ratios in Fig. 3. The average ionic concentrations and the average ionic ratios for the three places are shown in Table 1. The percentage of the excess concentrations of the different ions calculated on the assumption that chloride is a conservative property of sea spray particles is also given in the table. A brief summary of the behaviour of different constituents is given below. Concentrations are referred to in parts per million (ppm). The effects due to evaporation have not been considered.

Chloride — The day-to-day value varied widely (about one order of magnitude) at each place. The average chloride content present in rain samples and also probably in the airstream at the coast decreased to about one-third at the crest and to one sixth over the plateau (Table 1).

Sulphate — The average sulphate content decreased like that of chloride, at the crest but increased again in the plateau, unlike chloride, to about twice its value at the crest.

Sodium — The day-to-day value varied in wide limits both at the crest and in the plateau. The mean value decreased from the coast to the crest in the same manner as chloride. But, its further decrease from the crest to the plateau is much less than that of chloride.

Potassium — The average potassium concentration remained nearly steady from the coast to the plateau.

Calcium — This constituent also showed wide variation. The mean concentration decreasd at the crest to about half of its value at the coast and increased in the plateau to twice its value at the crest.

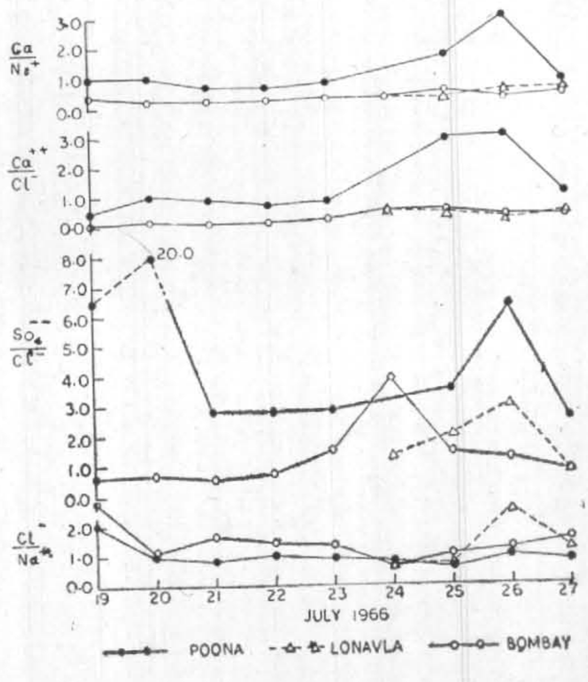

Fig. 3. Day-to-day variation of ionic ratios in rain water

Ratio of Chloride to Sodium — The ratio of these ions was found to be mostly less than the sea water value of 1·8 (Fig. 3). It varied from 0·6 to 2·8 on the coast; 0·7 to 2·5 at the crest and from 0·6 to 2·0 in the plateau. The value, on the mean, remained nearly the same from the coast to the crest (about 1·4) but decreased slightly in the plateau (1·0). Contribution to chloride by sources of industrial origin appears to be small at Bombay as otherwise the ratio of chloride to sodium would have been more than 1·8; Gorham (1958) found the ratios of 3 to 4 for pollution in England.

Ratio of Sulphate to Chloride — The value ranged from 0·6 to 3·9 on the coast as against 0·14 in sea water, indicating the possibility of continental contaminants like SO_2 pollution at Bombay. It varied from 0·8 to 3·0 at the crest and from 2·5 to 20 in the plateau. The mean ratio at the crest was one and half times that at the coast but in the plateau it was about five times as much. According to Gambell (1962), a ratio of less than one is indicative of marine dominance and more than one of continental influence.

Ratio of Calcium to Chloride — This ionic ratio varied from 0·1 to 0·5 on the coast as against 0·02 in sea water indicating considerable calcium concentrations on the coast. It ranged from 0·2 to 0·5 at the crest and 0·5 to 3·0 in the plateau. The mean ratio is nearly the same at the coast and the crest, and is about 0·3. It is as much as four times that in the plateau.

Ratio of Calcium to Sodium — The range of variation of this ionic ratio is, on the whole, small. The mean value on the coast is 0·3 as against 0·04 in sea water pointing once again the considerable amounts of calcium present on the coast. The value of the ratio at the crest is nearly the same as that at the coast, but it is 3 to 4 times more in the plateau.

The constituents measured, except for potassium, showed a somewhat similar trend of day-to-day variaton (Fig. 2). The feature indicates, as expected, that a good portion of the constituents originate from a common source. As the air flow is westerly (from the sea) upto 5 to 6 km during the monsoon period at the three places (on days of intense monsoon activity the westerly flow may extend upto 10 km), the moisture laden air from the sea is the main single source. The large excess values of sulphate, sodium, potassium and calcium in

TABLE 1

Average values of (i) concentrations (ppm) of different chemical constituents, (ii) their percentage excess (P.E.) and (iii) ionic ratios in rain water

	Cl^-	SO_4^{--}	P.E.	Na^+	P.E.	K^+	P.E.	Ca^{++}	P.E.	$\frac{Cl^-}{Na^+}$	$\frac{SO_4^{--}}{Cl^-}$	$\frac{Ca^{++}}{Cl^-}$	$\frac{Ca^{++}}{Na^+}$
Santacruz, Bombay (Coast)	4·4	3·8	533	3·2	33	0·6	582	0·9	900	1·4	1·3	0·3	0·3
Lonavla (Crest)	1·3	1·4	600	1·1	57	0·5	1823	0·5	1566	1·3	1·8	0·4	0·4
Poona (Plateau)	0·7	2·6	2500	0·9	125	0·6	4186	1·0	7046	1·0	5·9	1·4	1·2

rain water at the coast as indicated in Table 1 suggests continental influence on the oceanic airmasses in so far as their aerosol state is concerned. It is not clear to what extent the industries which are specifically upwind of the sampling site (the sampling site at Bombay is about 3·2 km from the coast, but is downwind of some industries) would have contributed to the observed excess values. The large excess values of sulphate (Junge 1963) and calcium (Stevenson 1968) reported over England have attributed to the heavy industries in the region.

The general trend of decrease of all the constituents in rain water at Lonavla as compared to at Bombay (Fig. 2 and Table 1) suggests that production of aerosols by local sources on the way is negligible. The increase in concentration of sulphate and calcium ions in rain water in the plateau region (figures in Cols. 3 and 9 of Table 1) indicated enrichment of maritime airmasses by aerosol of land origin after their entry into the plateau. Also the values of excess concentration of the different ions (figures in Cols. 4,6,8 and 10 of Table 1) markedly increased in the plateau region. The finding further confirms that the maritime airmasses crossing the crest are significantly influenced by aerosols of plateau region.

Considering the mean values of the ionic ratios, chloride to sodium, sulphate to chloride and calcium to chloride (Table 1), these are about the same both on the coast and at the crest. However, the values differ markedly on approach into the plateau. As the atmospheric chloride is largely resident on giant (radius 1 micron and more) sea-salt aerosols (Junge 1954), the comparatively high values of sulphate to chloride and calcium to chloride and the low values of chloride to sodium in the plateau region suggest marked depletion of the giant sea-salt aerosols in the airstream as it enters the plateau. As the giant sea-salt nuclei contribute to the precipitable size cloud droplets (precipitation particles), clouds in the plateau region are depleted considerably of the droplets in the large size end which are essential for formation of raindrops. The clouds on the lee side tend to become, therefore, stable. Further, the increase noticed in the mean value of the sulphate ion from the crest (1·4) to the plateau (2·6) indicates enrichment of this component from sources on the plateau. No such enrichment has taken place in the case of chloride indicating scarcity of chloride sources in the plateau. If it is considered that atmoshperic sulphate is mostly resident on aerosols in the large size range (radius 0·1 to 1·0 micron) as pointed out by Junge (1954), such aerosols of plateau origin become condensation centres for the formation of additional cloud droplets. As a result, the gross droplet population in clouds on the lee side increases, rendering them colloidally more stable. It is of interest to note in this connection that modification of the cloud drop spectrum by aerosols from local sources, such as sugar cane fires, has been pointed out (Warner and Twomey 1967). Also, there is marked increase in the value of the ionic ratio, calcium to sodium in the plateau region as compared to what it is at the crest. This increase is more due to enrichment of the calcium ion than due to depletion of sodium from sources on the plateau region as measurements indicate. Analysis by Gambell (1962) of Junge and Werby's maps of calcium and sodium concentrations for U.S.A. has also pointed out substantial increase of calcium for Colorado plateau which is a dry region.

By continued depletion of chloride from the coast to the plateau and enrichment of sulphate from the crest to the plateau, the number of precipitable size droplets would decrease and the total number of droplets would increase in the cloud downwind. Such droplet size distribution is characteristic of continental type clouds which do not normally rain unless they build up to considerable heights. But, lee waves produced downwind as a result of airflow over the mountains, though under certain conditions encourage convectin, generally damp the build-up of the cloud.

4. Implication of results on the design of experiments to stimulate rain in lee regions of Western Ghats

It may be considered that it will be possible to increase rainfall in the lee regions if clouds on the upwind side are made more stable so that their moisture content (liquid water) is retained for precipitation downwind (Bergeron 1949 and Weickman 1966). As clouds attain more stability under conditions of higher droplet concentration (for the same amount of liquid water content present, the average size of the droplet becomes smaller and, therefore, the coalescence process will have to operate much longer to result in precipitation), one method which can be considered for the purpose is injection of cloud forming nuclei in profuse quantities (these may be in the large size range, *i.e.*, 0·1 to 1·0 micron radius) into clouds in the upwind direction. But, the basic concept of any operation such as this may have to be critically examined. As at any time only a small fraction of the condensate is precipitated—according to Braham (1952) it is about 10 per cent in cumuli which reach thunderstorm stage and according to Elliot and Hovind (1964) it is about 25 per cent in orographic systems crossing the coastal range in the west of U.S.A.—it may not be specially helpful to seed the cloud in the upwind direction with a view to conserving its moisture content till it drifts downwind. Also, there is no certainty that the cloud so treated becomes once again colloidally unstable on the leeward side, specially in view of the present finding, namely, the aerosol content of cloud air in the plateau region becomes enriched with respect to sulphate and calcium. On the other hand, it appears to be more helpful if giant sized condensation nuclei are injected into the cloud in the upwind direction to help make up for the deficiency indicated of such particles (chloride) in the cloud air on the lee side.

5. Conclusion

The findings have been based on the chemical analysis of rain water samples collected at Bombay, Lonavla, and Poona. The number of days which the samples have been collected simultaneusly at these places is small, specially with reference to Lonavla. Simultaneous sampling, at a number of stations over an extended period during the monsoon season should furnish a more thorough picture of the changes which take place in the chemical state of the air after its entry into the plateau.

The present study indicates that clouds over the plateau have narrow dropsize spectra but higher droplet concentration as a result of (*a*) preferential depletion of giant chloride aerosols from the cloud air before its entry into the plateau and (*b*) addition of comparatively smaller aerosols from sources on the plateau. As the inference is only indirect, based on study of the chemical composition of rainfall, direct measurements of aerosols and of cloud droplet spectra at the crest and in plateau regions will help furnish a better insight into the micro-structure-stablility characteristics of clouds in the region.

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