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Further studies on electrical conductivity of monsoon rain water at Calcutta

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ABSTRACT. Study on electrical conductivity of monsoon rain water conducted by the author, was further continued in 1955, 1956 and 1958, and the results are reported in this paper—(*i*) The conductivity of rain water from different showers during a passage of a cyclonic storm near the station passed through a minimum which coincided with the maximum surface wind; (*ii*) Samples collected in thundershowers showed more or less regular variation with time counted from the start of rain. Towards the end of a thundershower conductivity K and intensity I of rainfall in some cases may be related by the equation $K \propto I^{-n}$ where n is a positive fraction; (*iii*) Samples from cumuliform clouds where no thunder was heard showed, in general, an irregular variation of conductivity; (*iv*) Rain from altostratus and preceded by long spells of rainfall or of heavy downpour may give water samples of the order of purity as conductivity water; and (*v*) Unlike some observations at Scandinavian stations, conductivity value of total water of a particular rainfall was never as low as that of conductivity water.

1. Introduction

Electrical conductivity of monsoon rain water at Calcutta in 1955 have been studied earlier (Mukherjee 1958). The study was further conducted in 1956 and 1958 with a view to understanding the variation of conductivity associated with rainfall from different types of clouds. The results of this study including some more observations in 1955 are reported in the present paper. The methods of collection and measurement of conductivity have been described in the previous paper (Mukherjee 1958). In the present study, a Royal Berlin porcelain basin of 10″diameter was used for collecting samples of rain water.

In 1955 and 1956 experimental works were conducted at the Jadavpur University premises. In 1958 it was done at the Barrackpore Observatory. The instruments and apparatus were loaned to the author by the Physical Chemistry department of the Jadavpur University for short periods.

2. Data

The data of conductivity are given in Tables 1 to 4. The data for 1955 refer to the rainfalls in association with the passage of a cyclonic storm. The rainfall during day time were collected in different fractions of a single fall. All those amounts were then stored in a well cleaned jena glass conical flask and the conductivity of the total water collected was measured later. The conductivity value, therefore, represents the conductivity of rain water from a particular shower taken as a whole. The collection at night was done in a different manner. On the night of 30 October 1955, there was a shower lasting for nearly 45 minutes. Only the approximate times of commencement and cessation of rain has been noted. One sample could be collected for the particular shower. In Table 1 are given the values of conductivities measured in the manner stated above.

In 1956, the period chosen for collection of the experimental samples was from 23 to 26 September, prior to which intermittent moderate rain was being received at the station for a few days. The purpose of the study in that year was to examine the purity of water from monsoon rainfalls as will be evident from the discussion of results given below.

TABLE 1

Conductivity of rain water from different rainfalls

Date	Time (IST)	Volume collected (cc)	Specific conductivity (mhos)
			$\times 10^{-6}$
29-9-55	1400—1422	280	7·08
30-9-55	1000—1025	410	4·53
	1210—1307	462	4·54
	2100—2200	354	4·96
1-10-55	1000—1031	450	5·96

The study of purity was again taken up in 1958. It appeared from a preliminary examination of 1956 data that only under some favourable circumstances we can get very pure water from a particular fall of rain. Moreover, it also appeared that there may be some connection between the type of cloud from which the rain is falling and the purity of the water sample collected. In 1958 the collection and measurement of rain water were done at Barrackpore Observatory. The conductivity apparatus was available only on some days. The results of experiments in 1956 and 1958 are given in Tables 2, 3 and 4 after classifying them for different types of clouds from which rain was falling. It should be mentioned here that the data in Table 1 refer to measurements done within 24 hours of the collection whereas those in Tables 2, 3 and 4 refer to measurement of electrical conductivity carried out immediately after the collection of water samples.

3. Discussion

From the nature of the data given in the tables, it is quite obvious that those given in Table 1 should be discussed separately in the context of weather situation.

3.1. *In association with a cyclonic storm*—On 29 September 1955, monsoon trough extended upto the head Bay of Bengal where the conditions were markedly unsettled. At 1730 IST, it formed into a depression centred at Lat. 18°N and Long. 90°E, becoming a cyclonic storm centred at Lat. 19·5°N and Long. 88°E at 0530 IST of 30th. On analysis of the synoptic charts for 29 and 30 September and for 1 October 1955, we find that Calcutta came under the influence of a developing storm on the afternoon of 29 September. The maximum influence was probably at about the noon of 30 September. Rain fell throughout the day on the 30th although wind never became very strong at the station. The influence became gradually less afterwards. The hourly wind data for Alipore Observatory confirm this view.

It would appear from Fig. 1 that when the wind speed was the highest and the influence of the storm was maximum, the conductivity recorded a minimum value. It is, however, to be expected that as the rain continues, the air becomes more and more free from substances which can be dissolved in rain. Thus what is expected is a gradual decrease in conductivity. But actually conductivity attained a minimum value and rose later.

The possible explanation of such a behaviour is that in the beginning the salts are washed out of the air and, therefore, the salt concentration of rain water and hence conductivity decreases. But a time comes (probably when a station gradually becomes free of influence of the storm or depression, which moves taking away the rainy zone associated with it) when the station in question starts getting air from a zone where the rainfall has already ceased. Normally it is maritime air at Calcutta. The conductivity of rain water decreased from 29th to 30th in the normal course. But from the afternoon of 30 September when the influence of storm was becoming less Calcutta was being fed with maritime air from comparatively drier areas. As we know, the maritime air always contains sea salts. Therefore, air containing salts was coming over Calcutta and was being washed out by falling rain drops. Thus it passed through a conductivity minimum.

This explanation is only tentative. However, this observation is interesting. It is proposed to study more cases before a conclusion can be reached.

TABLE 2
Thundershowers

Date	Time (IST)	Interval (min)	Volume (cc)	Specific conductivity (mhos)
				$\times 10^{-6}$
29-6-1958	1245—1250	5	72	14·2
	1250—1255	5	78	13·2
	1255—1300	5	31	16·2
	1300—1308	8	42	12·1
	1308—1313	5	64	7·6
	1313—1318	5	45	8·5
	1318—1323	5	28	10·4
30-6-1958	1053—1058	5	82	20·3
	1058—1101	3	110	5·9
	1101—1104	3	58	6·8
	1104—1107	3	34	9·1
	1107—1114	7	28	12·7
4-8-1958	1541—1544	3	90	17·1
	1544—1546	2	27	18·9
	1546—1548	2	24	13·1
	1548—1550	2	70	11·3
	1550—1552	2	60	10·7
	1552—1554	2	78	10·5
	1554—1556	2	98	9·8
	1556—1558	2	91	9·3
	1558—1600	2	106	9·0
	1600—1602	2	103	8·9
	1602—1604	2	112	8·2
	1604—1606	2	116	7·9
	1606—1607	1	53	7·7
	1607—1608	1	94	7·5
	1608—1609	1	160	7·0
	1609—1610	1	138	5·9
	1610—1611	1	112	5·5
	1611—1612	1	106	5·1
	1612—1613	1	98	4·7
	1613—1614	1	105	4·2
	1614—1615	1	98	4·0
	1615—1616	1	110	4·0
	1616—1617	1	119	3·8
	1617—1618	1	68	3·8
	1618—1619	1	79	3·4
	1619—1620	1	71	3·4
	1620—1621	1	76	3·6
	1621—1622	1	110	3·7
	1623—1624	1	82	4·3
	1624—1625	1	32	5·2
	1625—1626	1	53	3·0
	1626—1627	1	36	3·8
	1627—1628	1	20	5·2

TABLE 3
Rain from cumuliform clouds

Date	Time (IST)	Interval (min)	Volume (c.c.)	Specific conductivity (mhos)
				$\times 10^{-6}$
23-9-1956	1600—1615	15	50	13·3
	1615—1625	10	80	8·3
	1625—1635	10	80	6·1
	1635—1645	10	60	8·0
	1645—1655	10	50	7·1
	1655—1715	20	50	10·1
	1715—1745	30	30	22·3
24-9-1956	0950—0955	5	40	15·2
	0955—1000	5	48	11·2
	1000—1007	7	55	9·7
	1007—1017	10	90	8·0
	1017—1047	30	36	29·6
12-7-1958	1817—1825	8	29	29·7
	1825—1840	15	22	48·0
13-7-1958	1741—1745	4	23	41·1
	1745—1748	3	40	26·0
	1748—1750	2	15	38·3
15-7-1958	1114—1119	5	22	60·0
	1119—1122	3	41	22·2
	1122—1125	3	20	14·4
	1125—1130	5	23	25·1
	1130—1138	8	23	34·2
16-7-1958	1233—1236	3	96	10·7
	1236—1238	2	98	15·3
	1238—1240	2	64	11·5
	1240—1242	2	37	12·6
	1242—1246	4	42	6·5
	1246—1249	3	37	17·6
	1249—1253	4	40	15·7
	1253—1257	4	55	14·1
	1257—1300	3	20	8·0
17-7-1958	1735—1739	4	40	31·3
5-8-1958	1739—1742	3	84	9·0
	1742—1744	2	114	4·2
	1744—1746	2	116	3·4
	1746—1747	1	51	4·8
	1748—1749	1	37	4·2
	1750—1751	1	32	5·5
	1751—1752	1	28	5·7
	1753—1754	1	30	3·1
	1754—1755	1	30	3·6
	1755—1756	1	22	3·0
	1757—1759	2	25	3·6
	1800—1802	2	40	2·4
	1802—1804	2	22	7·2

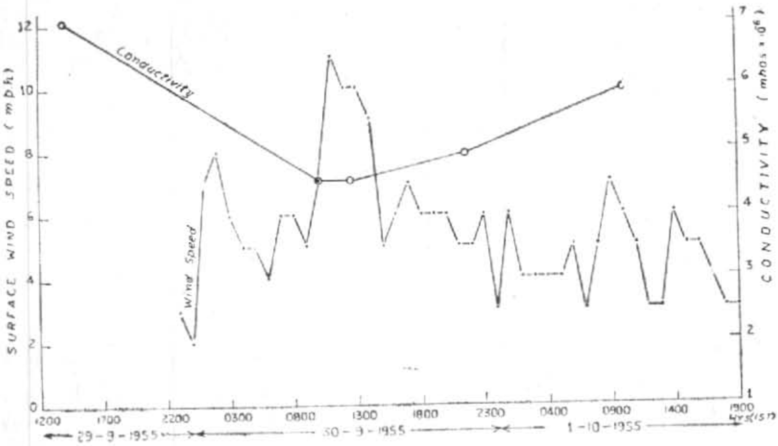

Fig. 1. Variation of conductivity of rain water and surface wind speed with time

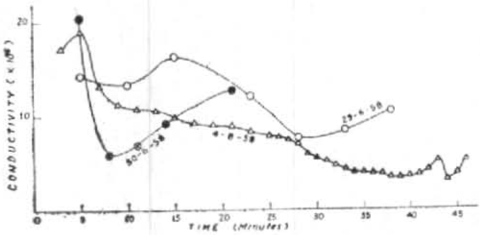

Fig. 2

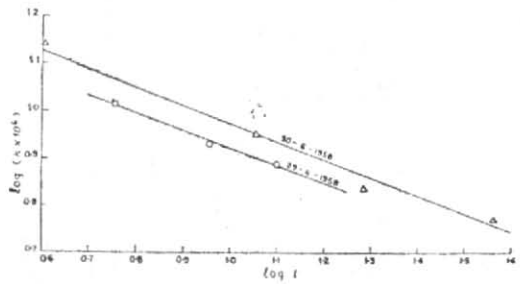

Fig. 3

3·2. *Thundershowers*—It has been reported in a recent paper (Mukherjee 1959) that the conductivities of rain water samples collected from thundershowers show some regularities. They are—(*i*) the conductivity of rain water gradually decreases with progress of rain, passes through a minimum and increases again towards the end when the shower becomes light, and (*ii*) during the period of gradual increase in conductivity K with simultaneous decrease in intensity I of rainfall, the plot of log K against log I is a straight line with negative slope. It is for this reason that the conductivity data for thundershowers have been shown separately in Table 2.

In Fig. 2, the conductivities of rain water samples collected from thundershowers against the time elapsed from the start of rain have been plotted for the three cases of thundershowers obtained for the present study. It will be seen from the figure that only on 30 June 1958, the conductivity decreased first and then gradually increased upto the end. On 29 June 1958 the graph shows two minima. On 4 August the fall in conductivity with time is not smooth. Here also we get two minima.

In Fig. 3, log of conductivity has been plotted against log of intensity of rain (measured as the volume of water collected per minute) for last three values of the rainfall of 29 June and for the last four values for that on 30 June 1958. They are found to be straight lines with slopes—0·38 and—0·39 respectively.

3.3. *Rain not accompanied by thunder*—In Tables 3 and 4 are given the conductivity data for water samples collected from rainfalls not accompanied by thunder. The general feature is that the variation is irregular. It may, however, be noticed that the data for 24 September 1956 and for 15 July 1958 show good regularity. As in thundershowers, conductivity decreased first and then increased again towards the end when the intensity decreased considerably. In the latter case log K was plotted against log I but no straight line was obtained.

3.4. *Purity of water samples*—A sample of water having specific conductivity between 1×10^{-6} mhos and 3×10^{-6} mhos is termed conductivity water. This is the purest water available in a chemistry laboratory. In our present series of investigation we find that the samples collected on 26 September 1956, and those collected between 1813 and 1828 IST of 4 August 1958 and also the sample collected at 1802 IST of 5 August 1958 are of that order of purity. These observations need a closer study to understand the reason for the high degree of purity of the rain water samples.

The meteorological conditions that prevailed over the Bay of Bengal during the week 19 to 26 September 1956 favoured the daily occurrence of rainfall at Calcutta. The seasonal trough of low pressure lay over the central and adjoining north Bay on 19 September. It persisted in the same position for the next three days and gradually concentrated over the northwest and adjoining west central Bay. By the morning of 23 September, it extended from the west central and northwest Bay to east Madhya Pradesh and became active over northwest Bay. It continued so with little change till 25 September when it moved westwards across Gangetic West Bengal causing widespread and exceptionally heavy rain over the area. Alipore (Calcutta) Observatory registered a fall of 6·24″ of rain during the 24 hrs ending 0830 IST on 26 September. Intermittent moderate rain continued at Calcutta till 1400 IST on this day. It is seen from the data given in the table that on the last day of

TABLE 4

Rain from altostratus

Date	Time (IST)	Interval (min)	Volume (cc)	Specific conductivity (mhos)
				$\times 10^{-6}$
26-9-1956	0750—0805	15	50	1·83
	0805—0818	13	58	1·98
	0818—0828	10	20	1·83
	0828—0853	25	46	1·84
	0853—0920	27	34	2·03
	0920—0940	20	32	2·80
	0940—0955	15	37	2·50
	0955—1015	20	27	2·49
4-8-1958	1738—1742	4	20	15·7
	1742—1747	5	25	17·1
	1747—1752	5	34	6·3
	1752—1757	5	24	7·9
	1757—1802	5	36	9·1
	1802—1807	5	40	3·6
	1808—1813	5	43	4·8
	1813—1818	5	38	2·3
	1818—1823	5	27	2·5
	1823—1828	5	18	3·0

measurement in 1956, the rain water was generally devoid of dissolved substances. This high degree of purity is ascribable to the fact that the continuous rainfall during the preceding days would have left the atmosphere greatly unpolluted.

The data for 1958 show that only some samples had a high degree of purity. It may be noticed that the very pure samples collected on 4 August were from a rainfall which occurred about an hour after a spell of heavy rainfall. In this case also the atmosphere was cleaned by the previous rainfall. The one sample on 5 August was also towards the end of a moderately heavy rainfall.

It may be noticed that the purest samples of rain water were from stratiform clouds although samples of rain water from other clouds were occasionally pure like conductivity water.

Cloud particles condense over condensation nuclei which are usually hygroscopic substances and electrolytes. Rain results from combination of such cloud particles. It is, therefore, not clear why the rain water samples should have purity as high as conductivity water. We have to search for a continuous and efficient dilution process acting in the rain bearing cloud which may only explain the high purity.

The Bergeron process of rain formation is essentially a dilution process. It may, therefore, be assumed that the rain falling from altostratus — nimbostratus combination during monsoon may be caused by Bergeron process. But some recent observations on precipitating nimbostratus clouds in monsoon (unpublished) indicate that Bergeron process may not be operating in those clouds. The rain is formed by collision, coalescence mechanism only. In that case any efficient dilution process is difficult to find out. Possibly after a growing raindrop breaks within the cloud into different fragments, the smaller ones ramain in the cloud for a longer time and grow by condensation. This process if continued for a long time may cause great dilution and the resulting rain water may be very pure. This is the only known process of growth of cloud particles by accretion mechanism accompanied by dilution. But a study of rate of growth by condensation (Mason 1957) indicates that this process is not an efficient one. However, no other dilution process is visualised in the rain formation process discussed.

3.5. *Purity of rain water of a shower*— The high order of purity of rain water samples discussed above refer to individual samples which are fractions of a particular continuous rainfall. In all cases pure samples were obtained towards the end of the fall. In case of samples of 26 September 1955, they also refer to those collected at the end of a continuous rainfall. However, if we calculate the conductivity of the total water from a particular fall, by using the formula

$$\overline{K} = \Sigma K_i \ V_i \ / \Sigma V_i$$

where $\overline{K}$ is the conductivity of the mixture composed of mixing water samples, K_i and V_i are electrical conductivity and volume of i^{th} sample, we find that the water is not as pure as conductivity water. This may be due to two causes—(*i*) The washing out of salts from air in between the cloud and the ground and (*ii*) Initial high concentration of salts as condensation neuclei in cloud particles. It may be reasonably assumed that the dilution process will not make itself pronounced in the beginning of rain but only after some time has elapsed from the start of rainfall.

A comparison with the data obtained in other countries will be interesting in this connection. The data for chemical composition of atmospheric precipitation published regularly in *Tellus* show that normally the Scandinavian rain water samples have got quite high values of conductivity. But some isolated cases have also been reported where the electrical conductivity of the total rain water collected in a month (probably there was only one rainfall in each case) showed purity of the order of conductivity water as can be seen from Table 5.

TABLE 5

No.	Place	Date	Conductivity (mhos)
1	Yágåmo	May 1956	2×10^{-6}
2	Flahult	Nov 1957	1×10^{-6}
3	Sala	Jan 1958	2×10^{-6}

Due to reasons given above such high degree of purity is not expected. It is, therefore, difficult to understand why it was so.

4. Acknowledgement

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