

Chemistry of monsoon rains over Calcutta, West Bengal

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सार — कलकत्ता (पश्चिम बंगाल) में सन् 1984 (जून से सितम्बर) के मानसून के दौरान वर्षा के छने हुए जल के कुल 50 नमूने (0.45 माइक्रो मी०) इकट्ठा किए गए। इन नमूनों का मुख्य लघुलेश मात्रिक तत्वों के लिए विश्लेषण किया गया है। अब तक प्राप्त विश्लेषित आंकड़ों से यह पता चलता है कि विभिन्न रासायनिक घटक, विभिन्न मौसम वैज्ञानिक कारकों पर निर्भर थे। बाइकार्बोनेट प्रमुख ऋणायन है जबकि कैल्शियम प्रमुख धनायन है। वर्षा जल के समग्र रसायन पर निकटवर्ती समुद्र का अधिक प्रभाव प्रतीत होता है। अधिकतर आयन समुद्री स्रोत से उत्पन्न होते हैं किन्तु समुद्रेतर क्रिया भी वर्षाजल के रसायन में महत्वपूर्ण भूमिका निभाती है। इस अध्ययन के दौरान वर्षाजल में लैण-मात्रिक तत्वों की सांद्रता का भी पता लगाया गया है। इसके अतिरिक्त पश्चिम बंगाल के ऊपर वायुमंडलीय दृष्टिपात अकार्बनिक अवयवों (इस समय SO_4 , NO_3 और Cl) के निवेश का एक मोटा सा अनुमान लगाया गया है तथा उसे इस शोधपत्र में लिखा गया है।

ABSTRACT. During the monsoon of 1984 (June-September), in all 50 filtered (0.45 μm) rainwater samples were collected from Calcutta (West Bengal) and the samples were analysed for major, minor and trace elements. The analytical data, so far obtained, reveals that different chemical components are depended on different meteorological factors. Bicarbonate is predominant anion whereas calcium is predominant cation. Nearby sea seems to have greater influence on overall chemistry of rainwater. Most of the ions originate from marine origin but non-marine activity also plays an important role towards rainwater chemistry. Trace elements concentrations in the rainwater have also been reported during the period of study. Further, a rough estimation of input of inorganic constituents (presently SO_4 , NO_3 and Cl) from the atmospheric precipitation over the West Bengal has been calculated and reported in this paper.

1. Introduction

Very little information towards chemical composition of monsoon rainwater over a particular area/region in India is available, although significance of some of the chemical constituents in rains to agriculture as well as in other fields also is well established. Rainwater is one of the chief weathering agents and its chemical composition provides significant knowledge for many geochemical investigations, water supply for human consumption, agriculture and monitoring of environmental pollution. Very few works in this regard have been reported in the literature (Narayanswami 1939; Handa 1969; Subramanian and Saxena 1980; Das *et al.* 1981, Mukherjee *et al.* 1985). After Handa, no detailed works have so far been carried out towards chemical composition of monsoon rainwater over Calcutta. Moreover, the author did not report any trace elements analysis over Calcutta. As such, after a lapse of about 16 years, a reappraisal study has been carried out by the present author during the period of monsoon rain in 1984. In this paper, the general observations so far obtained from this study on major, minor and trace elements chemistry of the rains over Calcutta and sources and variation of different chemical constituents in rainwater are briefly discussed. Further, an attempt has been made to calculate tentatively the input of some of the inorganic components through atmospheric precipitation over some districts of West Bengal.

2. Experimental

The rainwater samples were collected in polythene tubs as per procedure outlined by Das *et al.* (1981). Just after collection, water samples were filtered through 0.45 μm membrane filter (Millipore, USA) and the filtered waters were stored in polythene bottles for their subsequent analysis for major, minor and trace elements. In addition to total rains, different fraction of the rains in a particular day were collected in order to know the variation of different constituents with time.

Analysis of major, and minor ions was carried out as per procedures recommended by Das (1977) and Das *et al.* (1981). Determination of trace elements was carried out by different methods :

(a) *Atomic absorption spectrophotometry* — Solvent extraction procedure involving complexing of the metals such as Cu, Co, Cd, Ni, Pb, Cr and Zn by sodiumdiethylthiocarbamate at pH $3.6 \pm .1$ and extracting the metal complexes into methyl isobutylketone (MIBK) as per method outlined by Nix & Tom (1970) was adopted. The organic extract of the metal complexes were aspirated in air-acetylene flame (Varian Techtron AA6 Atomic Absorption Spectrophotometer) against proper reagent blank prepared under the same experimental condition at their respective wavelengths.

(b) *Spectrophotometric method* — Arsenic in rainwater samples was determined spectrophotometrically forming

TABLE 1

Chemical analysis data of monsoon rains over Calcutta during the period of June-September 1984 (in mg/l)

Date (1984)	Rainfall (mm)	pH	EC ($\mu\text{S/cm}$)	HCO ₃	Cl	SO ₄	NO ₃	Ca	Mg	Na	K
Jun											
2	14.3	6.4	50	19	10	5.2	0.9	8.0	2.0	2.8	0.25
3	68.5	6.9	55	18	4.5	3.8	0.5	6.2	1.70	2.2	0.30
4	140.6	6.2	35	10	5.2	4.5	0.3	6.5	0.97	1.25	0.24
5	289.9	5.9	58	12	9.5	4.2	0.2	2.8	0.85	1.80	0.25
8	67.5	6.5	30	4.9	2.8	3.8	0.5	0.8	2.00	1.10	0.31
9	28.6	6.9	28	6.8	2.2	3.0	0.15	1.4	0.48	0.51	0.20
18	26.7	7.1	65	15	3.8	3.2	0.21	6.8	1.90	2.30	0.40
19	45.8	6.9	30	5.8	5.2	3.6	0.11	3.5	0.49	1.40	0.36
22	139.7	6.2	25	3.9	4.5	3.0	0.60	2.0	0.38	0.48	0.18
Jul											
1	8.3	7.0	20	2.5	1.5	2.9	0.12	0.6	0.25	0.20	0.12
4	7.8	6.8	30	10	2.2	2.8	0.10	4.0	0.52	0.78	0.58
5	35.8	6.0	35	10	3.1	3.3	0.21	4.10	0.51	0.78	0.59
8	26.8	6.9	60	18	9.9	4.8	0.51	12.8	1.20	0.48	0.90
9	31.6	6.8	38	15	2.9	1.3	0.15	2.9	0.95	1.0	0.31
16	28.3	7.2	22	6	2.4	3.5	0.28	2.0	0.91	1.5	0.16
17	47.7	6.5	30	8.5	1.9	1.3	0.22	3.8	0.65	0.85	0.40
18	35.4	6.8	38	12	3.8	4.2	0.35	4.8	1.25	3.25	0.51
22	23.3	7.1	20	5	0.89	2.1	0.16	1.6	0.24	0.48	0.36
28	44.4	7.2	25	4	3.20	2.0	0.20	2.5	0.35	1.90	0.35
31	14.0	6.9	21	5	0.80	2.0	0.18	1.9	0.26	0.87	0.27
Aug											
1	10.1	6.8	25	5	1.50	3.8	0.21	2.2	0.30	0.68	0.36
2	13.0	6.9	40	15	4.5	2.9	0.28	11	0.85	3.50	0.84
3	69.3	7.2	42	18	4.0	3.8	0.25	6.2	1.50	3.10	0.41
7	22.8	7.3	35	13	3.8	3.1	0.21	1.8	0.62	1.15	0.31
9	45.5	6.5	28	5.5	2.8	1.8	0.20	4.6	1.20	2.20	0.35
10	17.7	6.9	40	12	4.6	3.5	0.19	6.8	0.65	2.80	0.49
13	28.1	7.0	23	4.5	1.5	2.15	0.10	1.2	0.24	1.52	0.32
14	10.7	6.8	15	2.8	3.2	0.75	0.18	0.6	0.35	1.50	0.25
16	41.8	7.1	18	2.5	1.0	3.51	0.21	1.8	0.08	0.65	0.18
20	29.2	7.2	25	6.8	2.2	3.2	0.08	1.5	0.91	1.45	0.31
22	43.4	6.9	35	18	9.8	5.2	0.10	11.5	0.95	4.5	0.80
25	78.0	6.9	45	16	9.1	6.2	0.18	9.1	2.8	4.20	0.80
31	16.0	7.0	20	5	1.5	3.2	0.10	0.78	0.28	0.28	0.32
Sep											
2	10.2	6.5	30	8.5	2.5	3.5	0.28	2.90	0.85	1.90	0.42
4	12.3	7.1	40	12.5	4.2	3.5	0.30	4.0	1.18	1.82	0.35
8	7.7	7.2	18	3.7	1.8	4.8	0.18	1.8	0.52	0.23	0.19
9	5.2	7.1	30	11.0	2.8	3.5	0.20	2.8	0.95	1.50	0.22
11	24.9	6.9	28	7.2	3.5	2.8	0.35	3.2	2.58	0.98	0.42
16	2.2	6.8	30	8.9	1.9	2.9	0.08	4.0	0.85	2.2	0.35
17	8.6	7.0	20	3.5	1.0	2.8	0.28	1.0	0.28	0.50	0.18
19	7.1	7.1	23	7.0	5.1	2.5	0.25	4.6	0.28		

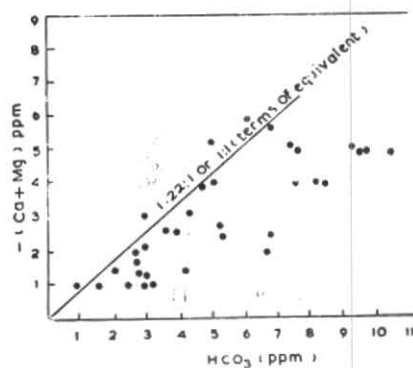


Fig. 1. Variation of alkaline earth metal as a function of bicarbonate ions

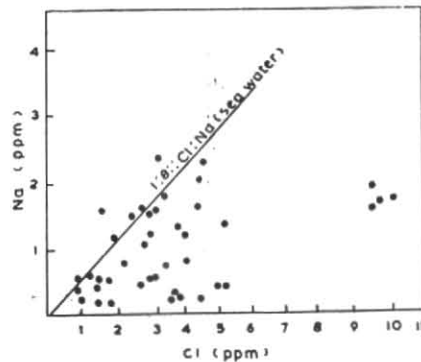


Fig. 2. Variation of sodium concentration as a function of chloride ion concentration in monsoon rains over Calcutta

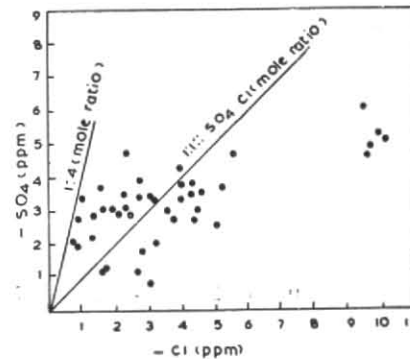


Fig. 3. Inter-relationship between concentration of sulphate and chloride ions in monsoon rainwater over Calcutta.

a red colour complex using silver diethyldithio carbamate in pyridine and its subsequent determination spectrophotometrically at 535 nm (Bausch and Lamb, Spectronic-20).

(c) *Flameless cold vapour technique* — This technique was adopted for determining mercury in some rainwater samples. Rainwater was treated with SnCl_2 to liberate mercury in gaseous stage which is then passed through mercury analyser MA 5800B (Electronics Corporation of India, Hyderabad).

3. Results and discussion

The chemical analyses data of 41 monsoon rainwater samples over Calcutta during 1984 with the total rainfall are given in Table 1.

Calcutta, the capital of West Bengal, is one of the thickly populated and industrial cities in India. It is located near Bay of Bengal on the left bank of river *Hooghly*. Three distinct seasons are observed: Summer, Monsoon and Winter. June-September are the monsoon months and southwest monsoon causes rains over the city. The rainfall is erratic and depends on various meteorological parameters. Sometimes strong wind with dust starts just before it rains and contributes considerable amount of dissolved constituents.

Rainwater falling through the atmosphere, scavenge part of the metallic and non-metallic constituents normally present in the atmosphere. It also dissolves some gaseous compounds of the atmosphere, released during combustion of coal, wood, fuels, automobiles etc. Further sea-salt nuclei may also be regarded an important source of chemical constituents in the rainwater.

A look into the chemical results as shown in Table 1 reveals that rainwater contains various amounts of different chemical constituents, *i.e.*, major, minor and trace elements. A brief discussions are being made based on the results obtained so far from the analysis of rainwater over Calcutta.

(a) *pH* — The minimum and maximum value of pH are 5.9 and 7.2 respectively with an average value of

6.3. pH of the neutral rainwater should be 5.7 at 25° C which is the value for CO_2 in equilibrium with the solution at the existing partial pressure. Mukherjee in his series of papers (1957, 1964, 1978) nicely discussed various factors controlling the pH of the rainwater.

(b) *HCO₃ ion* — It is a major constituent in all rainwaters and highest concentration so far recorded is 19 mg/l. Its concentration varies a good deal from shower to shower. This ion is produced by the reaction of the carbonic acid with alkaline earth-bicarbonates present in soil, dust or otherwise in the atmosphere as a particulate matter. In Fig. 1, calcium plus magnesium (calculated in terms of calcium in mg/l) is plotted against bicarbonate value in mg/l of the analysed rainwater samples. It shows that major portions of the analysed samples lie on the right side of the reference line, *i.e.*, 1.22 : 1 or 1 : 1 in terms of the equivalent, indicating presence of part of alkaline metal bicarbonate in the atmosphere whereas waters falling on the left-side of the reference line indicate some of the magnesium ions may be of marine origin. Average value of the ion is around 9.0 mg/l. Its concentration in the first shower of a particular day is relatively high which gradually decreases with time due to washing down of the soluble bicarbonates. But this phenomenon is not always true and in a few instances last fraction shows somewhat higher value under exceptional condition.

(c) *Cl ion* — Chloride is another major constituent in rainwater. It is cyclic in nature. Sea is the major source of this ion in the rainwater (Junge and Gustafson 1967, Egner and Erikson 1955, Gambell and Fisher 1964). Calcutta is very near to Bay of Bengal and as such this may be regarded as an important source of chloride in rainwater. In certain cases, soil dust particles may also contribute this ion to rainwater in a considerable amount. Experimental facts also suggest that concentration of chloride in rainwater along seacoast is comparatively higher than that of inland rainwater. Its concentration is always greater than Na and weight-ratios are somewhat higher than Cl : Na in sea water, *i.e.*, 1.8 : 1 (Hem 1970). Fig. 2 shows plottings of Na values against Cl values of the rainwater. It is seen from the figure that some of the water samples plot on

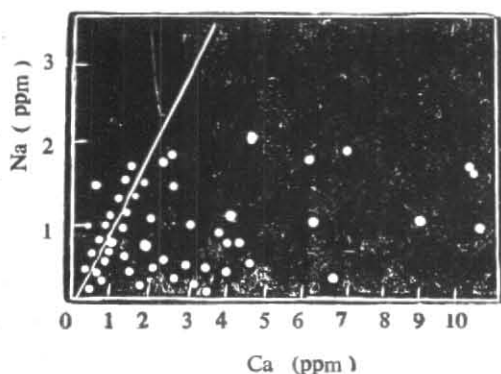


Fig. 4. Plot of sodium against calcium concentration in monsoon rainwater over Calcutta

(St. line represents 1 : 1 :: Na : Ca (mole ratio))

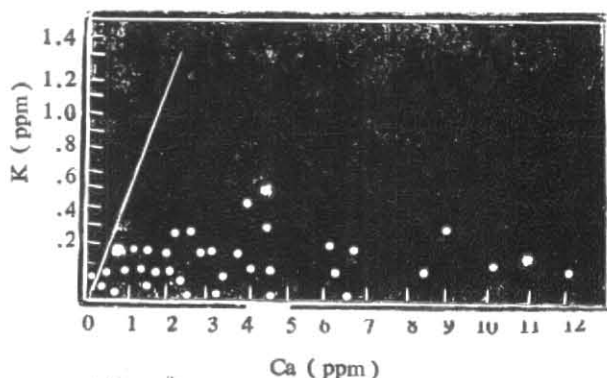


Fig. 5. Plot of potassium vs calcium concentration in rainwater over Calcutta

(St. line represents 1 : 1 :: K : Ca (mole ratio))

the reference line, i.e., 1.8 : 1 indicating same ratio to that of sea water. Rest of the water samples plot on either sides of the line which obviously indicate local source of this ion in rainfall. Experimental evidences also suggest that concentration of this ion, like bicarbonate ion decreases with time due to washing out of the major part of the chloride ion as shower continues, but the results vary a good deal in day-to-day showers. The Cl:Na ratios in some of the rainwaters, collected from the different fractions of a continuous shower vary a lot and some values fall on the reference line while the others do not. The average value of Cl is 4.0 mg/l.

(d) SO_4 ion — Many of the water samples have SO_4 ion concentration somewhat greater than the chloride ion concentration. The sulphate values are plotted as a function of chloride values (Fig. 3). It is observed that many of the water samples plot on the right side of the 1 : 1 line which indicates that, in addition to the local factors, sulphate in the rainwater may be originated from sea-salt nuclei also. The local source of this ion in rainwater may also be due to combustion of coal, petroleum, wood etc. Perusal of analytical results also reveals that chloride concentration in some rainwaters exceeds sulphate ion concentration. This phenomenon possibly occurs during cyclonic weather. SO_4 ion also shows a gradual decrease in concentration with time but erratic values are also observed. The average value is around 3.5 mg/l.

(e) NO_3 — Analytical results show presence of this ion in all fraction of the rainwaters whose values vary a good deal ranging from 0.08 mg/l to 0.9 mg/l with an average value of 0.45 mg/l. Various scientists put forward different opinions about its mode of occurrence in atmosphere. It is generally believed that sources of this ion in rainwater are probably due to atmospheric reactions (thundering and lightning), gaseous, fuels, land mass etc. Huchingson (1944), Angstrom and Hogberg (1952 a & b), Mukherjee (1955), Gambell and Fisher (1964), Viemeister (1960) and Vissar (1964) studied the different factors responsible for occurrence of nitrogen in rainwater.

(f) Ca ion — In all water samples so far analysed from Calcutta, calcium ion predominates and its concentration

exceeds sodium and magnesium except in one case where magnesium ion concentration exceeds calcium. The source of this ion is likely to be derived from soil dust particles and sea. The marine and non-marine origins of calcium in rainwater are confirmed by plotting of calcium ion concentration against sodium ion concentration (Fig. 4). In sea water, concentration of calcium is 400 mg/l, compared to 19,000 mg/l for chloride (Hem 1970). It gives weight ratio being 47.5 : 1. Also weight ratio of Na : Ca in sea water is 26.25 : 1. From Fig. 4, it is seen that many of the water samples fall on the right side of 1 : 1 line which suggests continental origin of the ion in rainwater. This finding is also supported by the following ratios of Ca : K and HCO_3 : Ca. In sea water, the weight ratio of Ca and K is 0.95 (Fig. 5) and that of HCO_3 and Ca is 0.3 (Hem 1970). The analytical results show this ratio exceeds above value. The variation of calcium follows same pattern as to bicarbonate. However, exceptions are there.

(g) Mg ion — Concentration of Mg in rainwater is comparatively low within the range of 0.08 mg/l to 2.8 mg/l. In all cases, except one, its concentration is much less than calcium. In sea water, concentration of Ca is 400 mg/l and that of Mg is 1350 mg/l which gives a weight ratio of Ca and Mg as 1 : 3. This ratio in rainwater samples is not same as that of sea water. From Fig. 1, it is seen that many rainwater samples plot on left hand side of the reference line of 1.22 : 1. It indicates that some of the magnesium and even calcium are originated from the sea. It is also evident from Fig. 1 that land mass also contributes this ion in rainwater considerably. Concentration of this ion also decreases with passage of time, but in some showers erratic behaviour is also observed.

(h) Na ion — The concentration of this ion in rainwater is normally less than calcium. The source of this ion is likely to be marine and non-marine origin, but it would be rather difficult to calculate its relative contribution to rainwater from two different sources. Chloride and sodium ion concentrations in sea water are 19,000 mg/l and 10,500 mg/l respectively, which gives a weight ratio as 1.8 : 1. In Fig. 2, concentration of chloride ion in the rainwater samples is plotted

TABLE 3-12

Percentage distribution of families by income classes and family size

Sl. No.	Family size	Monthly family income classes (Rs.)										Total	Percentage of families to total
		< 60	60 to < 100	100 to < 150	150 to < 200	200 to < 300	300 to < 500	500 to < 750	750 to < 1,000	1000 to < 1,500	1500 & above		
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	One	—	—	2.29	9.82	29.30	26.14	20.52	5.05	3.82	3.06	100.00	23.15
2	Two and three	—	—	—	—	0.97	30.67	42.28	8.05	8.79	9.24	100.00	22.32
3	Four and five	—	—	—	—	1.05	30.83	33.61	21.98	12.53	—	100.00	28.99
4	Six and seven	—	—	—	—	—	6.15	29.43	12.89	44.11	7.42	100.00	15.83
5	Eight and nine	—	—	—	—	—	—	26.82	15.47	42.15	15.56	100.00	6.80
6	Ten and above	—	—	—	—	—	—	—	7.40	50.13	42.47	100.00	2.91
	Total	—	—	0.53	2.27	7.30	22.81	30.41	12.65	17.79	6.24	100.00	100.00
	No. of families (Estimated)	—	—	126	540	1,738	5,430	7,239	3,011	4,235	1,486	23,805	

TABLE 3-13

Percentage distribution of families by monthly per capita income classes and family size

S. No.	Family size	Monthly per capita income classes (Rs.)										All Classes
		< 45	45 to < 60	60 to < 75	75 to < 100	100 to < 125	125 to < 150	150 to < 200	200 to < 250	250 & above		
1	2	3	4	5	6	7	8	9	10	11	12	
1	One	—	—	—	—	2.85	2.22	10.26	27.07	59.87	23.15	
2	Two and three	—	—	—	1.99	10.83	16.98	28.24	22.03	34.71	22.32	
3	Four and five	—	100.00	72.40	41.60	60.03	41.02	29.49	32.50	1.25	28.99	
4	Six and seven	—	—	23.35	39.15	10.15	10.62	26.42	10.16	4.17	15.83	
5	Eight and nine	—	—	4.25	15.27	16.14	10.21	5.59	8.24	—	6.80	
6	Ten and above	—	—	—	1.99	—	18.95	—	—	—	2.91	
	Total	—	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
	Percentage of families to total	—	0.02	4.17	10.85	7.56	14.23	22.16	12.85	28.16	100.00	
	No. of families (Estimated)	—	5	993	2,583	1,800	3,387	5,275	3,059	6,703	23,805	

CHAPTER 4

FAMILY INCOME AND RECEIPTS

4.1 Concepts and definitions

Data relating to family income were collected in order to study the level and pattern of income by sources, to study expenditure in relation to income and in general to provide a basis for classifying families into economic levels. Income, for the purposes of survey, was taken to mean all receipts which did not result in diminution of assets or an increase in liabilities and included:

- (i) Income from paid employment consisting of basic wages/allowances, bonus and commission, overtime earnings, other benefits and concessions;
- (ii) Income from self-employment such as those from boarding and lodging services, agriculture, animal husbandry, trade and profession; and
- (iii) Income from other sources such as rent, pension, cash assistance, gifts and concessions, interest and dividends, chance games and lotteries, etc.

Data were also collected in respect of other receipts of family arising through the disposal of assets or creation of new liabilities such as sale of shares and securities, withdrawal of savings, sale of other assets, credit purchases, loans taken, etc. The value of the receipts in kind and of goods from family enterprise consumed by the family was imputed on the basis of retail market prices.

All the data relating to income and receipts were collected for the calendar month preceding the date of the survey in respect of each sampled family. The analysis of data is given below:

4.2 Income by classes and sectors

Table 4.1 gives the average monthly income per family and per capita by monthly income classes.

Table 3.11—concl.

Percentage distribution of families by family composition in terms of adults/children and monthly income classes

Sl. No.	Family composition in terms of adults/children	Monthly family income classes (Rs.)				Number of families (Estimated)	
		750 to < 1,000	1,000 to < 1,500	1,500 & above	Total		
1	1	10	11	12	13	14	15
1	One adult	5.05	3.82	3.06	100.00	23.15	5,511
2	One adult & children	100.00	—	—	100.00	0.06	14
3	Two adults	14.90	5.45	7.70	100.00	9.18	2,185
4	2 adults and 1 child	—	15.25	7.29	100.00	8.88	2,114
5	2 adults and 2 children	9.22	—	—	100.00	7.77	1,850
6	2 adults and more than 2 children	24.87	23.31	—	100.00	17.95	4,273
7	Three adults	8.77	2.51	16.88	100.00	4.19	997
8	3 adults and children	17.13	33.44	—	100.00	13.11	3,121
9	Other families	14.37	40.59	22.09	100.00	15.71	3,740
	All families	12.65	17.79	6.24	100.00	100.00	23,805

TABLE 2

Trace elements analyses data of some of the rainwater samples collected from Calcutta during monsoon of 1984 ($\mu\text{g/l}$)

Date (1984)	Cu	Co	Zn	Cd	Ni	Pb	Cr	As	Hg
05 Jun	25	10	50	<0.2	<0.2	12	<4.0	<0.4	<0.1
22 Jun	18	5	42	<0.2	5	8	<4.0	<0.4	<0.1
16 Jul	2	<0.2	20	5	4	15	<4.0	<0.4	<0.1
28 Jul	15	18	71	<0.2	<0.2	20	<4.0	<0.4	<0.1
31 Jul	12	8	28	<0.2	<0.2	21	<4.0	<0.4	<0.1
13 Aug	5	6	30	<0.2	<0.2	<4	<4.0	<0.4	<0.1
16 Aug	9	7	55	<0.2	3	8	<4.0	<0.4	<0.1

as a function of sodium ions which shows many samples plot either on or near the 1.8 : 1 (Cl : Na) line, *i.e.*, in the same proportion as they present in the sea water indicating marine origin. Variation of this ion with progress of rains also follows the same pattern as in the case of other ions.

(i) *K ion* — Concentration of this ion is very low in comparison to other major elements. The weight ratio of K : Na is much higher than that of sea water. In sea water potassium ion concentration is 380 mg/l and that of sodium is 10,500 mg/l giving weight ratio of these ions as 0.04. But calculated weight ratios of the analysed samples are much higher than that of sea water. Further, the weight ratio of Ca/K is 0.95 (Fig. 5) but in the case of rainwater, the ratio is much higher than this ratio indicating non-marine origin. It is evident from Fig. 5 that few samples lie near the reference line indicating marine origin. The rest of the samples lie far away from the line indicating non-marine origin.

(j) *SiO₂, Fe and PO₄* — A few rainwater samples were subjected to these analyses indicating their presence in detectable amount. The source of these ions is likely to be from the terrestrial non-marine origin.

(k) *Trace elements* — Few 0.45 μm filtered water samples were preserved by the addition of A.R. HNO₃ (pH=1.5-2.0) for the analysis of Cu, Ni, Pb, Zn, Cr and Cd. Another set of filtered samples was preserved by the addition of a few ml 1M NaOH for the determination of As. Further for the determination Hg, the samples were preserved by the addition of K₂Cr₂O₇/H₂SO₄. These elements were analysed by different physico-chemical techniques as mentioned earlier. The results of analysis are shown in Table 2. Perusal of analytical results reveals that most of the trace elements are present in the rainwater in measurable quantity but the concentration of Cr, As and Hg are present below their detection limit. Cd is detected in one sample only and in other cases it is present below their detection limit. Perusal of results also reveals that their occurrence in the rainwater do not follow a definite pattern. The presence of these

trace elements may be due to the presence of dust particles in the atmosphere. It is worth mentioning that determination of trace-elements in rainwater requires further detailed studies using more sophisticated instrumental techniques having capability of measuring very low concentration of various trace elements. The Inductively Coupled Plasma Atomic Emission Spectrometer (Plasma Analyser) is being commissioned in the Central Chemical Laboratory of Geological Survey of India. This versatile instrument will be of immense use for determination of large number of elements in the rainwater. Table 2 shows concentration of nine trace elements in seven rainwater samples for Calcutta.

(1) *Rainfall distribution over the different districts of West Bengal*

Amount of rainfall over different districts of West Bengal from 1 June 1984 to 19 Sep 1984 are given in Table 3. Average normal rainfall over the individual district is calculated based on the rainfall from 1900 to 1984. Monsoon rainfall started from 1 June 1984 and ended on 19 Sep 1984. From the table it is seen that distribution of rainfall is not evenly distributed among all districts and percentage of rainfall is always more than the average rainfall over the individual district of West Bengal.

(m) *Salt input* — The chemical constituents present in rainwater are one of the most important sources of ions in groundwater which after intense evaporation (and evapotranspiration also) may increase their concentration several folds. However, after falling on the earth, much of the rainwater passes away as surface run-off and a fraction of it, depending on the geology of the area, ultimately joins groundwater gradually after satisfying soil moisture conditions. The process of accumulation and increment of chloride in the groundwater, *i.e.*, the chloride budget in parts of Madhya Pradesh has been described by Das *et al.* 1983. In the present discussion, an estimation of the total amount of some of the chemical constituents in kg/km² area, deposited on the surface *via* rainfall over Calcutta and other districts around it, *i.e.*, the southern part of

TABLE 3

Distribution of rainfall over different districts of West Bengal (from 1 Jun to 19 Sep 1984) and their variation from av. normal rainfall

Districts	Amount of rainfall (mm)	Normal rainfall (mm)	Deviation from av. normal rainfall (%)
Darjeeling	2667	2206	+21
Jalpaiguri	3226	2516	+28
Coochbehar	3146	2576	+22
West Dinajpur	1782	1431	+25
Malda	1100	1019	+8
Murshidabad	1236	983	+26
Nadia	1572	843	+67
Birbhum	1407	915	+54
Burdwan	1318	1081	+22
Hooghly	1527	1043	+46
Bankura	1531	1047	+46
Purulia	1306	971	+35
Midnapore (E)	1580	1112	+42
Midnapore (W)	1904	1083	+76
Howrah	1842	1128	+63
24 Pgs. (N)	1636	1043	+57
24 Pgs. (S)	1929	1186	+63
Calcutta (Alipore)	1902	1128	+68

TABLE 4

Amount of deposited sulphate, chloride and nitrate over Calcutta and other districts of West Bengal

Districts	Total deposited amount in kg/km ²		
	Sulphate	Chloride	Nitrate
Burdwan	4,613	5,272	583
Hooghly	5,344	6,108	687
Bankura	5,358	6,124	689
Purulia	4,571	5,224	588
Midnapore (E)	5,530	6,320	711
Midnapore (W)	6,678	7,632	859
Howrah	6,447	7,368	829
24 Parganas (N)	5,726	6,544	736
24 Parganas (S)	6,741	7,704	867
Calcutta	6,657	7,608	856

TABLE 5

Weight ratios of some of the important ions in rainwater samples obtained from different parts of India

Ratio	Sea water	Present work (1984)	Delhi (Khemani & Ramamurthy 1968)	Calcutta (Handa 1969)	Bombay (Sadasi-van 1979)	Pune (Khe-mani 1974)	Pune (Mukh-erjee 1985)
Ca/Na	0.038	2.3	4.60	3.27	0.40	1.37	1.15
K/Na	0.036	0.31	0.63	0.37	0.07	0.31	0.28
Mg/Na	0.12	0.29	—	0.50	0.12	—	0.37
Ca/K	1.0	9.9	7.30	8.80	5.60	3.70	5.80

West Bengal, has been made taking into account of the total rainfall over individual district. Among various chemical constituents in the rainwater, presently sulphate, nitrate and chloride ions have been considered for computing their deposited amount over the southern part of West Bengal. The amount of salt input, thus obtained, is tentative, but the ultimate values will give a very good idea of the total deposited ions over a particular area.

From the chemical analysis, it is seen that average concentration of SO₄, Cl and NO₃ in the rainwater are 3.5 mg/l, 4.0 mg/l and 0.45 mg/l respectively. From these average values, we may get total amount of the deposited salts as sulphate, chloride and nitrate over Calcutta. Further, if we consider same concentration of these ions in the rainwater over the other districts near Calcutta (suppose up to the distance of about 200 km), we can get the total amount of these constituents over the southern part of West Bengal. Similarly we can compute the total amount of the other deposited ions also. The amount of deposited SO₄, Cl and NO₃ over Calcutta and other districts of West Bengal is shown in Table 4. From this table, it is observed that rainwater over the ten districts of West Bengal carries enormous amount of sulphate, chloride and nitrate to the earth. Deposited amount of chloride (5,224 to 7,704 kg/km²) is somewhat higher than the deposited sulphate (4,571 to 6,741 kg/km²) whereas amount of nitrate is much lower than the former two constituents.

(n) Comparison of the analytical value with other localities of the country

A comparison of the values of the mean ratio of Ca/Na, K/Na, Mg/Na and Ca/K between sea water and present study along with the values of the above ratio obtained from other three important cities of India (Delhi, Bombay and Pune) have been made and their values have been listed in Table 5. The results show that the values of Ca/Na in sea water is much less than that the values obtained from the other localities and its values increase with the distance from the sea, e.g., Bombay has the minimum value (0.40) whereas in Delhi, its value increases up to 4.60. The present

value of K/Na in Calcutta is comparable to the value obtained from Pune, but the value obtained from coastal station is about 4 to 5 times less whereas the same at Delhi is about doubled than that of present work. The present Mg/Na ratio is quite low than that obtained by Handa (1969). The Ca/K ratio so far obtained from present study is little higher than the value obtained by the previous work of Handa and this value is much higher than the other stations in India.

4. Conclusion

From the chemical analyses of monsoon rainwater from Calcutta during monsoon period of 1984, following conclusion can be drawn :

- (i) Most of the rainwaters have a tendency towards slightly acidic character.
- (ii) All major cations and anions are present in detectable amount. HCO_3 and Ca are the predominant anion and cation in the local rainwater.
- (iii) Although in the beginning of the first shower, bicarbonate ion predominates, its concentration, gradually diminishes with passage of time, but sometimes erratic values are also noticed and even in the last fraction of a continuous shower, high bicarbonate concentration is noticed.
- (iv) Most of the other cations and anions behave similarly as bicarbonate ions.
- (v) Concentrations of various chemical constituents are not constant in local rainwater and it differs from shower to shower. The same phenomenon is also observed in the rainwater from other parts of the country. It is also dependent on the various meteorological parameters.
- (vi) Different weight ratios such as Cl/Na, Cl/ SO_4 , HCO_3 /Ca, K/Na, Ca/Na, Mg/Ca and Ca/K etc have been calculated and their values are compared with the sea water. The results indicate the influence of nearby sea to a great extent. Moreover, non-marine origin such as dust particles, automobile exhaust, smoke, etc also contribute significant amount of the dissolved constituents in the local rainwater.
- (vii) Presence of a number of trace metals have been reported in the rainwater in detectable amount, but their concentration does not follow a definite pattern. However, further studies in this regard are required.

(viii) Districtwise normal rainfall over the entire State of West Bengal have been calculated based on the rainfall from 1900 to 1984. The values indicate that the monsoon rainfall during 1984 exceeds normal rainfall in all districts.

(ix) Amount of deposited salts (SO_4 , Cl and NO_3) over some of the districts has been calculated indicating a significant amount of salts deposited *via* rainfall.

(x) Weight ratio of some of the important ions have been shown and their values are compared with the other localities of the country. It shows great variation of the ratios from one place to another.

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