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Chemical composition of monsoon rainwater over Bhopal, Madhya Pradesh (India) during 1977 and 1978

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ABSTRACT. A preliminary and systematic study of the chemical composition of monsoon rainwater over Bhopal has been carried out during the years 1977 and 1978. The analytical results reveal that the total minerals of the rainwater is governed by the meteorological and geographical parameters. A definite pattern, however, could not be ascertained and the concentration of different ions vary considerably. Bicarbonate is the predominant anion and calcium is the predominant cation. Most of the ions originate from the non-marine sources, although marine origin is also likely to contribute for the presence of some ions in the rainwater. The presence of trace elements such as strontium, copper, zinc, manganese and iron have been recorded but lithium and nickel could not be detected in the local rainwater samples during the period.

1. Introduction

Rainwater having distinctive quality pattern, has got a significant function in regional, national and continental water quality. It is one of the chief agents in rock weathering and main source of groundwater. As such its chemical composition provides a significant knowledge for many geochemical investigations, particularly in groundwater quality evaluations. Apart from this it relates to water supply for human consumption, agriculture, industry and above all for monitoring of environmental pollution.

In Europe, United States, Australia and other foreign countries, a considerable work in this regard has been carried out (Eriksson 1959, 1960; Junge 1958; Emanuelsson, Eriksson and Egner 1954; Carroll 1962). In India, although a number of raingauge stations have been set up to measure the total rainfall in all parts of the country and to calculate and estimate the run-off, evapotranspiration, recharge to groundwater etc., very little informations about the chemical composition of rainwater are available. However, some work have been carried out by Narayanaswamy (1939) and Handa (1968, 1971).

After a close survey of the published literature, it reveals that no analytical data on chemical composition of rainwater over Bhopal is available. As such a systematic study is being carried out by the authors on the chemical composition of monsoon rainwater over Bhopal during the years 1977 and 1978. In the present paper, a brief discussion on chemical composition of rainwater and the sources of some of its chemical constituents including trace elements are outlined.

2. Experimental

The rainwater samples were collected in polythene tubs as per recommended procedures. The clean and washed polythene tubs were placed on a long stool (about 4′ high) on the terrace of the projects' Chemical laboratory for collection of the rainwater samples. After collection (mostly immediately), the water samples were filtered through 0.45 m μ membrane filter (Milipore, USA) using hand pump to separate the suspended matters and stored in a cleaned polythene bottle for subsequent analysis.

The following analytical techniques were adopted for determining the major and minor chemical constituents present in rainwater :

(*i*) *pH* — The Philip's "precision pH" meter (PR 9405 M) and Orion 407A

specific ion meter (Orion Research Incorporated, USA) with their respective electrodes, standardised by the buffers 4.0, 7.0 and 9.2 respectively, were used.

(*ii*) *Electrical Conductivity* — EIL (UK), portable conductivity meter using 0.1 cm cell was used for this determination.

(*iii*) *Bicarbonate* — Acidimetric titration using methyl orange-bromocresol green mixed indicator was used. In few cases potentiometric method was adopted using Orion 407A meter and the equivalence point was obtained from the graph.

(*iv*) *Sulphate* — Usually gravimetric procedure as $BaSO_4$ was adopted. Visual titrimetric procedure using thorin as indicator and $Ba(ClO_4)_2$ as titrant was also adopted in few water samples.

(*v*) *Chloride* — Determined with Orion 407A meter using Orion selective ion electrode.

(*vi*) *Nitrate* — It is determined by UV-method using "Unicam-SP-6-500" Ultraviolet-Visible Spectrophotometer at 220 nm. A correction was made at 275 nm for organic matter. The phenoldisulphonic acid method using Bausch and Lomb (Spectronic-20) was also used for few samples for the colorimetric determination of nitrate.

(*vii*) *Calcium and Magnesium* — These two constituents were determined by UNICAM-SP-1900 Atomic Absorption Spectrophotometer using multi hollow cathode lamp at the wave lengths : 422.7 nm (Ca) and 285.2 nm (Mg) respectively.

(*viii*) *Sodium and Potassium* — Atomic Absorption Spectrophotometric methods (SP-1900) using respective hollow cathode lamps at the wave lengths of 589 nm (Na) and 766 nm (K) respectively were used.

(*ix*) *Silica* — Molybdenum blue method by reduction of heteropoly acid was adopted and determined spectrophotometrically (SP-6-500) at 700 nm.

(*x*) *Boron* — Determined spectrophotometrically at 620 nm by dianthramide method.

(*xi*) *Fluoride* — Orion 407A selective ion meter using fluoride electrode.

(*xii*) *Phosphate* — Spectrophotometric method of molybdenum blue at 882 nm was used.

In addition to the above constituents, a few rainwater samples were concentrated 10-20 times in presence of few drops of 1 : 1 nitric acid (ANALAR, BDH) and then determined using UNICAM-SP-1900 Atomic Absoprtion Spectrophotometer for Strontium (461.5 nm), lithium (671.5 nm), copper (325.5 nm), zinc (213.9 nm), nickel (232.5 nm), iron (248.3 nm) and manganese (279.5 nm) respectively following the techniques recommended by the manufacturer (Pye-Unicam) and Das (1977) respectively.

3. Results and discussions

The chemical analysis of monsoon rainwater samples during the years 1977 and 1978 have been given in Table 1 and Table 2 respectively for major and minor ions and Table 3 shows the chemical analysis of trace elements found in few rainwater samples collected over Bhopal from the chemical laboratory.

Close scrutiny of the analytical results of the rainwater samples reveals that the following generalised features could be drawn which may be taken into consideration for the interpretation of the analytical data.

(*i*) pH of the rainwater samples are generally feebly acidic in nature with an average value of around 6.2.

(*ii*) Bicarbonate is dominant in the anions and calcium in the cations forming calcium bicarbonate type of water.

(*iii*) In the first shower the bicarbonate ion predominates which gradually decreases with subsequent rainfall although some exceptions are observed at times.

(*iv*) The chemical composition of the rainwater is not constant and differs from one shower to another, without any order or fashion.

(*v*) The salinity of the first shower is somewhat higher than the subsequent showers. Similarly it is also dependent on the intensity, duration of rainfall and interval between the successive showers, but a significant correlation could not be made among the above parameters with the salinity.

(*vi*) The weight ratio of Na^+/Ca^{++} and Cl^-/SO_4^{--} values of the rainwater in 1977 and 1978 are calculated and it is found that in most of the cases the ratio exceeds unity when the intensity of rainfall is high, but in normal cases the ratios are less than unity.

(*vii*) The average weight ratio of Cl^-/Na^+ and HCO_3^-/Ca^{++} in the analysed samples are 5.86 and 3.08 respectively, but the values are not constant and in some cases these values go below 1.10 and 1.0 respectively.

(*viii*) The nitrate ions are invariably present in all analysed rainwater samples.

(*ix*) The sulfate is also present in all samples and the 50 per cent values are generally less than chloride.

(*x*) Iron, boron and silica have been detected in all samples and as a matter of fact their values are not constant among

TABLE 1

Chemical analysis data of monsoon rainwater over Bhopal during the period June-August 1977 (in mg/l)

S. No.	Date of rainfall (1977)	pH	EC in μmhos/cm at 25°C	HCO_3	Cl	So_4	NO_3	Ca	Mg	Na	K	Fe
1	25 June	6.5	50	21.9	2.7	3.8	0.5	4.4	1.6	1.2	0.27	0.04
2	25 June	6.9	30	8.5	2.3	2.8	0.9	2.4	0.85	0.35	0.11	0.02
3	27 June	6.2	60	25.1	6.7	5.2	0.6	6.2	1.72	3.4	0.40	0.01
4	27 June	7.1	30	11.6	4.4	3.8	0.51	3.6	1.22	0.76	0.23	0.02
5	27 June	7.1	28	7.3	4.0	3.9	0.32	3.0	0.73	0.55	0.12	0.01
6	4 July	6.2	28	9.2	3.2	3.0	0.50	2.8	0.85	0.62	0.14	0.08
7	5 July	6.5	32	8.5	4.8	3.8	0.70	2.9	1.22	0.68	0.37	0.02
8	23 July	7.0	22	8.9	3.2	2.8	0.80	2.8	0.97	0.08	0.01	0.02
9	25 July	7.1	28	4.9	2.9	3.5	0.61	0.8	2.0	1.10	0.31	0.02
10	26 July	6.9	30	8.9	1.8	2.8	0.22	3.6	0.97	1.0	0.20	0.01
11	27 July	6.5	50	21.0	1.6	3.8	0.20	4.4	1.6	1.2	0.27	0.03
12	27 July	7.1	21	6.8	2.0	2.9	0.15	1.4	0.49	0.51	0.21	0.02
13	3 Aug	6.1	30	11.6	4.4	3.5	0.25	2.8	0.85	0.51	0.10	0.01
14	5 Aug	7.2	25	11.0	2.5	3.4	0.71	2.2	0.97	1.40	0.20	0.02
15	7 Aug	7.1	55	23.2	3.8	3.0	0.25	7.2	1.9	0.29	0.06	0.01
16	7 Aug	6.1	20	6.7	3.1	2.8	0.50	2.9	0.49	0.28	0.18	0.02
17	8 Aug	6.0	29	7.3	3.0	3.8	0.12	3.6	0.97	0.23	0.04	0.03
18	8 Aug	7.1	28	5.8	5.1	3.9	0.15	3.4	0.49	0.40	0.16	0.04
19	11 Aug	6.5	25	6.9	3.1	2.1	0.20	2.8	0.50	0.21	0.01	0.02
20	23 Aug	7.0	65	20.7	9.4	5.8	0.72	8.0	2.0	1.15	0.39	0.01
21	23 Aug	7.1	22	5.5	3.3	3.8	0.51	2.0	0.97	0.21	0.20	0.02
22	24 Aug	7.0	20	2.5	0.93	2.5	0.40	0.8	0.24	0.16	0.06	0.03
23	25 Aug	6.9	20	3.9	4.2	3.2	0.71	2.4	0.36	0.23	0.08	0.04
24	27 Aug	7.2	15	3.7	1.6	3.8	0.15	1.4	0.49	0.23	0.11	0.01
25	29 Aug	6.8	18	4.8	2.8	3.2	0.25	0.80	0.24	1.50	0.78	0.02
26	30 Aug	6.9	15	2.4	1.4	2.8	0.12	0.60	0.25	0.20	0.02	0.01

the different showers and are not related with the intensity of rainfall.

(*xi*) Fluoride is also detected and is generally around or less than 0.1 mg/l.

(*xii*) The analysis data on trace elements of few rainwater samples reveals the presence of strontium, zinc, copper and manganese.

Falling through the atmosphere, the rainwater carries some major, minor and trace elements, normally present in the atmosphere. The rainwater also dissolves some gaseous compounds from the atmosphere which are normally released during combustion of coal, petroleum products etc from the industries. Similarly storms containing dust and other foreign particles may contribute a significant amount of dissolved constituents to the rainwater. In addition to above factors, sea salt nuclei may also be regarded as an important contributor to these chemical constituents to the rainwater.

As the chemical analyses of the rainwater samples contain all major, minor and few trace elements, a brief discussions are being made about the possible sources of various chemical constituents in monsoon precipitation over Bhopal.

(*a*) *pH* — The pH of the rainwater varies from 6.0 to 7.2 with an average value of 6.2 indicating acidic character. Large amount of soluble atmospheric gases such as CO_2 and SO_2 cause the rainwater to act acidic which in turn, attack various metals and building materials such as concrete, marbel etc. Considering CO_2 above to be in equilibrium with atmospheric CO_2 the pH should be 5.7 at 25°C. However, Mukherjee

TABLE 2

Chemical analysis data of monsoon rainwater over Bhopal during the period April-September 1978 (in mg/l)

Date of rainfall (1978)	Rain-fall (mm)	pH	EC in μmhos/ cm	HCO_3	Cl	SO_4	NO_3	Ca	Mg	Na	K	SiO_2	Fe	F	B	PO_4
24 Apr	20.1	6.4	45	14.0	3.6	4.0	0.61	2.2	2.4	1.6	1.2	2.4	0.08	0.08	0.057	—
24 Apr	—	6.9	28	8.6	2.4	3.2	0.50	2.8	0.61	0.91	0.25	2.1	0.02	0.06	0.048	—
7 Jun	2.4	6.8	45	13.0	5.1	4.5	0.20	6.4	0.6	0.90	0.04	1.6	0.02	0.04	0.062	0.02
7 Jun	—	7.0	32	10.0	3.6	2.0	0.30	3.0	1.2	0.82	0.60	0.81	0.06	0.04	0.024	—
9 Jun	0.7	6.2	61	28.0	3.5	2.8	0.41	11.0	0.80	1.11	0.04	1.2	0.01	0.08	0.002	0.12
10 Jun	—	6.9	32	8.0	3.5	2.8	0.15	5.4	0.62	1.60	0.04	1.4	0.02	0.06	0.008	0.04
10 Jun	—	6.2	38	18.0	3.8	3.0	0.21	6.0	1.2	0.98	0.20	1.2	0.02	0.04	0.038	—
21 Jun	22.5	6.4	62	20.0	5.4	5.0	0.80	8.0	1.0	2.11	0.01	1.6	0.15	0.01	0.028	0.12
21 Jun	—	6.9	25	12.0	3.2	2.8	0.19	1.0	0.61	1.12	0.01	1.5	0.01	0.02	0.045	—
21 Jun	—	7.1	28	4.5	2.2	1.5	0.21	4.5	1.2	2.00	0.01	0.8	0.01	0.01	0.031	—
28 Jun	9.8	7.0	40	13.0	3.6	3.5	0.28	6.0	0.60	1.8	0.28	0.6	0.06	0.06	0.002	0.13
29 Jun	48.7	6.0	32	7.0	4.8	3.2	0.21	3.0	0.62	1.8	0.25	0.4	0.03	0.09	0.038	0.14
30 Jun	46.1	6.5	22	6.0	4.9	2.3	0.70	2.0	0.60	1.6	0.21	0.4	0.02	0.08	0.052	0.10
30 Jun	—	6.9	38	15.0	2.8	1.2	0.50	2.8	0.91	0.80	0.30	1.5	0.02	0.01	0.027	—
1 Jul	44.0	6.5	80	32.0	8.2	3.8	0.81	11.0	4.3	0.71	0.21	2.4	0.06	0.02	0.011	0.10
1 Jul	—	6.9	32	15.0	4.8	3.6	0.42	3.2	0.80	0.80	0.30	1.6	0.02	0.02	0.028	—
1 Jul	—	7.0	18	3.0	2.4	3.4	0.28	2.0	0.91	1.4	0.15	1.4	0.01	0.01	0.068	—
6 Jul	223.4	6.1	38	12.0	3.5	3.8	0.35	4.0	1.22	0.23	0.21	0.8	0.02	0.12	0.048	0.13
8 Aug	6.2	6.9	62	22.0	7.0	5.8	0.41	12.0	2.41	0.61	0.20	1.5	0.06	0.11	0.008	0.13
9 Aug	33.6	7.1	15	3.0	1.8	2.4	0.52	1.0	0.62	0.11	0.12	3.1	0.03	0.11	0.002	0.11
16 Aug	59.6	7.0	60	24.1	3.5	4.8	0.31	8.0	1.22	0.90	0.02	2.8	0.03	0.10	0.024	0.14
26 Aug	101.5	6.9	50	14.0	7.1	2.8	0.15	8.0	0.52	0.90	0.21	2.4	0.03	0.08	0.024	0.10
26 Aug	—	6.8	21	8.5	1.9	1.2	0.20	3.2	0.61	0.42	0.31	2.5	0.02	0.01	0.021	—
28 Aug	0.5	6.7	78	26.0	7.1	3.8	0.51	9.6	2.42	0.92	0.20	1.5	0.01	0.02	0.009	0.16
29 Aug	37.6	7.1	62	25.0	7.1	4.0	2.20	10.0	1.22	0.80	0.21	1.4	0.04	0.04	0.042	0.14
14 Sep	10.1	6.8	25	7.1	5.2	1.5	0.80	3.6	0.35	0.92	0.40	2.4	0.04	0.04	0.055	0.10
18 Sep	0.3	6.9	32	7.0	5.19	2.0	0.25	4.4	0.16	0.30	0.39	1.4	0.02	0.02	0.048	0.05

(1957, 1964, 1978) has shown that pH of monsoon rainwater is between 6.0 and 7.0. The acidic rainwater, is also responsible for weathering of rocks, soil minerals etc. However other dissolved consitituents buffer the rainwater at the above value.

(*b*) *Bicarbonate* — The bicarbonate ion is invariably present in almost all natural waters including rainwater, although their concentration varies widely and considerably depending on the source of water. This important constituent is produced by the reaction of water with atmospheric carbondioxide forming carbonic acid with the alkaline earth carbonates present in the environment as dust particles. In Fig. 1, a plotting of $Ca^{++}+Mg^{++}$ (calculated in terms of Ca^{++} in ppm) *vs* HCO_3^- in ppm is made on the basis of the analysis of rainwater samples during the monsoon of 1977 and 1978. From the figure it is seen that almost all analysed samples lie on the right side of the reference line of 1.22 : 1 (or 1:1 in terms of equivalent) which indicates definitely the presence of alkaline earth metals, even in small amounts, as bicarbonates in the atmosphere. The average bicarbonate ion concentration over Bhopal is 10.0 mg/l. Its value in the first shower is relatively high in comparison to the successive showers and gradually diminishes with time. But the general pattern is not consistent and sometimes the last fraction gives the higher value also under exceptional cases.

(*c*) *Chloride ions* — In accordance with the findings of Junge and Gustafson (1967), Egner and Eriksson (1955), Gambell and Fisher (1966) etc, it may be concluded that sea is the major and significant source of chloride ions in rainwater except in certain cases such as in inland

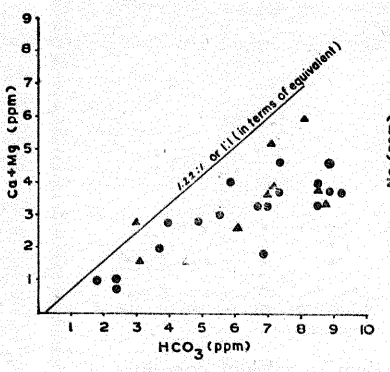

Fig. 1. Variation of alkaline earth metals as a function of bi-carbonate ions

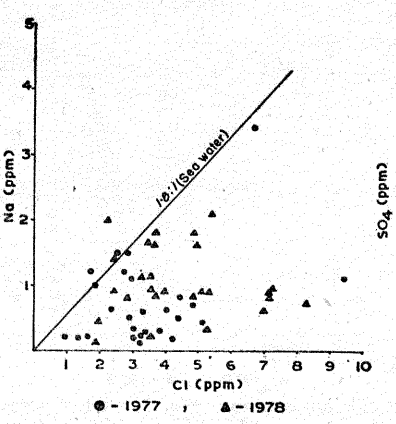

Fig. 2. Variation of sodium concentration as a function of chloride ion concentration in monsoon rainwater samples

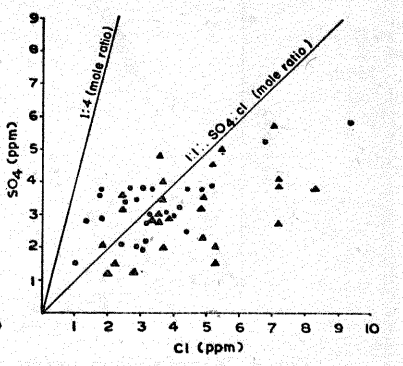

Fig. 3. Inter-relation between the concentration of sulphate and chloride ions in monsoon rainwater samples

areas where soil dust particles may also contribute this ion to rainwater in considerable amount. It is generally observed that its value in rainwater is highest along the sea coast and diminishes towards inland. The chemical data obtained so far from the analysis of rainwater during 1977 and 1978 reveals that the chloride values are greater than the sodium ion concentrations in rainwater and the weight ratios are also somewhat greater than the Cl^-/Na^+ ratio in sea water (1.8:1). A plot (Fig. 2) of Na^+ *vs* Cl^- values indicates that only a few rainwater samples fall on the reference line, indicating the same ratio in sea water. Most of the rainwaters lies on the right hand side of the 1.8:1 — line which obviously indicate that local sources play a significant role in contributing chloride in rainwater over Bhopal. It is also seen from the analytical data that the early part of the monsoon or at the first shower, the chloride concentration is higher and gradually diminishes with showers due to washing out of the major part of the dust particles from the atmosphere, although results vary considerably in day-to-day showers. It is also to be mentioned here that, in addition to the successive showers, some other factors, such as wind velocity, intensity of rainfall, topography of the area, are also the contributing factors affecting the total mineralisation of rainwater of a particular area. The average value of chloride over Bhopal is 3.4 mg/l. The Cl^-/Na^+ value also changes with time and shows a wide variation from the reference value of Cl^-/Na^+ ratio in sea water which conclusively proves that non-marine origin also plays an important role for the presence of chloride in rainwater over Bhopal.

(*d*) *Sulphate* — Appreciable amount of sulphate ions are present in rainwater over Bhopal and the values also vary considerably. About 50 per cent of the total analysed samples contain chloride comparatively less than sulphate values. The results are plotted in the Fig. 3 which indicates that 50 per cent water samples fall on the right side of 1:1 line which reveals that in addition to local factors, sulphate in rainwater may be originated from the sea salt nuclei also. The average value of sulphate in rainwater over Bhopal is 3.2 mg/l.

(*e*) *Nitrate ions* — Nitrate ions are present in all the local rainwater samples, although their concentrations vary considerably ranging from 0.12 to 0.88 mg/l with an average value of 0.5 mg/l. There exists much dispute among the scientists regarding the presence of the nitrate ions in rainwater and their mode of occurrence. It is generally believed that the sources of nitrate in rainwater are due to atmospheric reactions, gaseous fuel, land mass etc. Hutchingson (1958) concluded the chief source of nitrogen in rainwater is likely to be derived from the soil mass whereas Eriksson (1952) considers the fuel consumption to be an important source of nitrogenous compounds. The analytical results reveal that the average value of this ion is below 0.5 mg/l over Bhopal.

(*f*) *Calcium ions* — From the analysis, irrespective of the years, it is revealed that rainwater samples contain appreciable amount of calcium. The soil dust particles present in the atmosphere may be regarded as one of the chief sources for the ions. Sea salt may be disregarded as main source of calcium over Bhopal since it is situated far off from the sea (about 600 km). In sea water, the concentration of calcium is 400 mg/l as compared to that of 19,000 mg/l for chloride (Hem 1970) which gives the weight ratio being 47 5:1. Also the weight ratio of Na : Ca in sea water is 26.25:1. From the plotting of

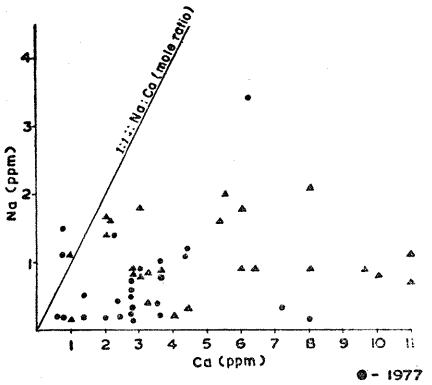

Fig. 4. Plot of sodium against calcium concentration in monsoon rainwater samples

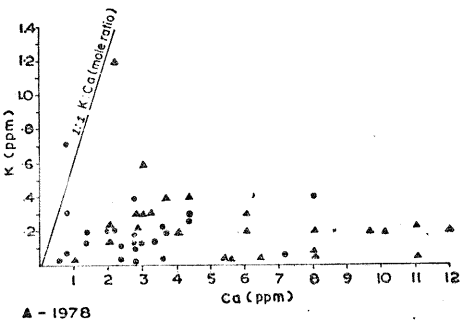

Fig. 5. Plot of potassium *vs* calcium concentration in rainwater samples over Bhopal

TABLE 3

Trace elements analysis in rainwater samples over Bhopal during the monsoon of 1978 (in mg/l)

Date (1978)	Sr	Cu	Zn	Mn	Li	Ni
24 Apr	0.030	0.008	0.051	0.005	Nil	Nil
10 Jun	0.028	0.004	0.041	0.005	Nil	Nil
29 Jun	0.002	0.002	0.021	0.001	Nil	Nil
1 Jul	0.001	0.001	0.010	0.002	Nil	Nil
8 Aug	0.004	0.002	0.017	0.004	Nil	Nil
16 Aug	0.002	0.006	0.076	0.002	Nil	Nil
29 Aug	0.024	0.003	0.020	0.003	Nil	Nil
18 Sep	0.008	0.006	0.046	0.004	Nil	Nil

Na^+ *vs* Ca^{++} in Fig. 4, it is seen that almost all samples fall on the right side of 1:1 line (in terms of mole ratio of $Na^+ : Ca^{++}$) and calcium ions always exceed the soduim ions except in few cases which confirms the continental origin of this constituent in rainwater over Bhopal. This is also confirmed by the following ratios of Ca^{++}/K^+ and HCO_3^-/Ca^{++}. In sea water the weight ratio of Ca^{++}/K^+ is 0.95 (Fig. 5) and that of HCO_3^-/Ca^{++} is 0.3, but in the case of rainwater these ratios are always greater than the above values. The rainwater analysis also indicates that average concentration of calcium is 3 mg/l. The variation of calcium in rainwater follows the same pattern as to bicarbonate ions, although some exceptions are also noticed.

(*g*) *Magnesium ions* — In almost all cases, the concentration of magnesium ions in rainwater does not exceed the concentration of calcium ions. In sea water the concentration of magnesium is 1350 mg/l and that of calcium is 400 mg/l. The weight ratio of these two constituents, Ca^{++}/Mg^{++} is 1 : 3. But in rainwater this ratio is not same as that of the sea water which indicates the terrestial origin of this constituent in rainwater over Bhopal. As such it appears that the major part of magnesium in rainwater is from the land mass. The average magnesium concentration in rainwater is 0.81 mg/l over Bhopal.

(*h*) *Sodium ions* — In general the source of sodium ions in rainwater is considered to be sea-salt nuclei as well as the dust particles, but as a matter of fact, it is quite difficult to ascertain its relative contribution to the rainwater from marine or non-marine origin. The chloride and sodium concentrations in sea water are 19,000 and 10,500 mg/l respectively which gives the weight ratio of Cl^-/Na^+ is 1.8. The same calculations with the rainwater samples show deviation from the above ratio. The Fig. 2. plots the Na^+ *vs* Cl^- values in mg/l and indicates almost all samples lie on the right side of 1.8:1 (Cl^- : Na^+ in sea water) line except four samples lie on the left side of the line. This indicates that the sodium ions are originated in the rainwater both from non-marine and marine sources. The mean average value of sodium over Bhopal is 0.80 mg/l and its value decreases with shower to shower and other meteorological parameters.

(*i*) *Potassium ions* — Although in almost all cases, the concentration of potassium is always less than that of sodium in rainwater, the weight ratio (K^+/Na^+) is much higher than that of sea water. In sea water the potassium ion concentration is 380 mg/l and that of sodium is

10,500 mg/l giving the K^+/Na^+ weight ratio (0.04) but calculated value of this ratio in the rainwater gives much higher than this value (0.04). As such it is obvious that non-marine origin plays a significant role for presence of this constituent in the atmosphere as well as in the rainwater over Bhopal. The average value of potassium in monsoon rainwater over Bhopal is 0.16 mg/l.

(*j*) *Boron* — Boron is determined only in 1978 monsoon water and it is found to be present in almost all samples. The values also vary considerably and no definite correlation could be found with the other constituents reported so far and also with the meteorological parameters discussed above. The main source of boron in rainwater is likely to be originated from volcanic sources as well as dust particles in the atmosphere. It may be assumed that the element boron, within the study area, is likely to be originated from the dust particles of terrestial substances. The minimum and maximum values of boron in rainwater are 0.002 and 0.068 mg/l respectively.

(*k*) *Silica, Iron and Fluoride ions* — Almost all samples reported so far in this paper contained silica and iron. A definite correlation could not be found with the other constituents present in rainwater. Fluoride is also reported to be present in a few rainwater samples, although its concentration lies within 0.1 mg/l and less. The presence of these constituents in rainwater may be assumed to be derived entirely from the terrestial origin.

(l) *Trace elements* — Using UNICAM-SP-1900 Atomic Absorption Spectrophotometer, Strontium, Zinc, Nickel, Manganese, Lithium and Copper were determined in few rainwater samples over Bhopal. The results, tabulated in the Table 3, indicate the presence of Strontium, Zinc, Copper and Manganese in few rainwater samples with the concentration ranging from Sr (1 to 30 ppb), Zn (10 to 76 ppb), Mn (1 to 5.0 ppb) and Cu (1 to 8.0 ppb). But the elements lithium and nickel could not be detected in the rainwaters over Bhopal. The absence of these two elements in rainwater may be attributed to be due to the fact that either rainwaters do not contain any of these two elements or their presence is below detection limit. It is, therefore, concluded that the presence of the above elements in monsoon rainwater may be attributed to the dust particles present in the atmosphere.

4. Summary

A preliminary and systematic investigations have been carried out during the monsoon period of 1977 and 1978 over Bhopal (Madhya Pardesh), India to ascertain the chemical composition of monsoon rainwater and their modes of occurrence. The rainwater samples were subjected to major, minor and trace element analysis by recommended procedures. The results indicate that the chemical composition of rainwater varies considerably from shower to shower. The local factors such as geology of the area, extent of industrialisation etc also play an important role for the chemical composition of rainwater. The calcium and bicarbonate ions are the most dominant ions. From the above discussions it is revealed that almost all chemical constituents present in rainwater over Bhopal are of non-marine origin. The location of Bhopal, a city farthest from the sea coasts, may also be significant in this respect. Some trace element analysis shows that rainwater contains strontium, zinc, manganese and copper in detectable amount, although their concentrations vary considerably, but lithium and nickel could not be detected in rainwater. Boron, iron, silica and fluoride are also detected in all samples except fluoride which is present in some rainwater below 0.1 mg/l. It is also assumed that these four constituents are of terrestial origin.

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