

MEASUREMENT OF pH AND CHEMICAL ANALYSIS OF RAIN WATER IN RURAL AREA OF INDIA

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ABSTRACT

Large number of rain water samples, at 7 rural locations in the semi-arid region of the Deccan Plateau were collected during 4 consecutive monsoon seasons (1979–1982). pH, conductivity and the major ionic components (Cl^- , SO_4^{2-} , NO_3^- , NH_4^+ , Na^+ , K^+ , Ca^{++} , Mg^{++}) of the above samples were determined. The pH of rain water was found to be highly alkaline and the values varied from 6.4 to 7.8. Soil-oriented elements showed good correlation ($r \sim 0.6$) with pH values of rain water. The high concentration of soil-oriented elements, specially Ca^{++} , is found to play an important role in neutralizing the acidity of rain water and maintaining high alkaline pH. The study suggested that the contribution of atmospheric aerosol of natural sources (sea and soil) to the chemical composition of rain water is more than that of anthropogenic origin.

1. INTRODUCTION

Acid rain, usually described as a European and North American problem, is spreading to the developing countries of the world. Although the developing countries consume one fifth of the world's commercial energy, the share is growing. Industry is also growing, so is the number of vehicles on the roads; many of the industries lack expensive pollution controls, and many vehicles, engines are badly maintained, resulting in an even greater proportion of air pollution.

India, one of the developing countries of the world, faces the problem of acid rain. Its annual sulphur dioxide emissions have trippled since the early 1960s. Air pollution is already severe in the metropolitan cities, like Calcutta, Delhi and Bombay (NEERI, 1980). Acid rain has already been reported since 1974 at Chembur, major industrial area in the city of Bombay (Mahadevan et al., 1984).

Many studies on the chemical composition of rain water in India are reported from the urban areas which are greatly influenced by the local industrial sources (Mukherjee, 1957, 1964; Khemani et al., 1968, 1982a, 1985b; Handa, 1969, 1973; Sequeira, 1976; Subramanian and Saxena, 1980; Das et al., 1981; Handa et al., 1982) and hence can not indicate the background pollution levels in the region.

In order to find out the background pollution in the atmosphere and long-range transport of pollutants, it is necessary to know the chemical composition of rain water samples in rural areas which are free from the sources of local pollution. Hence, a study on the chemical composition of rain water is undertaken in rain shadow region of the Western Ghats during four monsoon seasons from 1979 to 1982 at 7 rural stations. The results of the study consisting of temporal variation of ionic composition, long-range transport of pollutants, sources of the

pollutants and their influences on the pH of rain water are presented below.

II. LOCATIONS OF OBSERVATIONAL SITES

Since 85% of the annual rainfall in India occurs in southwest monsoon season (June—September), rain water samples have been collected at 7 rural stations, namely, Jamgaon, Ranjangaon, Sirur, Daund, Supa, Baramati and Wadgaon. The locations of the 7 stations are shown in Fig. 1. All these stations are about 200 km away from the west coast of India and

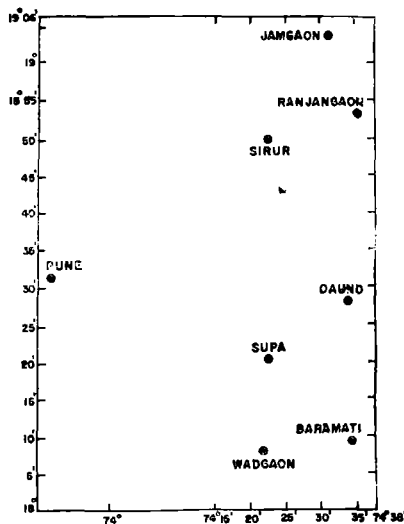


Fig. 1. Locations of observational sites. Scale: 1 cm=5 km.

are situated in the semi-arid region on the leeward side of the Western Ghats. This region is known as rain shadow area of the Deccan Plateau. West to east orography rises from the coast of Bombay and ends in a plateau at an average height of 0.6 km. The Western Ghats extend from north to south along the west coast. Rainfall during the southwest monsoon is strongly orographic on the windward side of the Western Ghats. Precipitation increases with altitude from the coast of the windward side and falls off sharply on the leeward side. Average seasonal rainfall during the southwest monsoon season is less than 40 cm at these observational sites. Rao (1976) has described, in detail, the occurrence of monsoon season in India.

III. SAMPLING AND ANALYSIS

Rain water samples were collected at 5 locations, namely, Ranjangaon, Sirur, Daund, Supa and Baramati during 4 summer monsoon seasons from 1979—1982. Samples at Jamgaon and Wadgaon were collected for 3 summer monsoon seasons from 1980—1982. Samples were collected using stainless steel funnels of 30 cm diameter fitted on 10 litre capacity polyethylene bottles previously rinsed with deionized water. The funnels were kept one meter above the ground level at all the stations. Each sample was collected in course of rainy day and contained volume of rain water varying from 100 to 1000 mL. All the rain water samples were filtered through Whatman's 41 filter paper and refrigerated at 4°C in the laboratory till all ionic components were analysed. The samples were analysed for anions (Cl^- , SO_4^{2-} , NO_3^-) and cations (NH_4^+ , Na^+ , K^+ , Ca^{++} and Mg^{++}). The concentrations of Cl^- , SO_4^{2-} , NO_3^- and NH_4^+ were determined by using colorimetric methods (Khemani et al., 1985), and those of

metallic components by using Perkin-Elmer 373, double beam atomic absorption spectrophotometer with air-acetylene flame.

pH was measured with digital pH meter using reference (KCl) and glass electrodes standardized with pH 4.0 and pH 9.2 reference buffers before and after pH determination. Conductivity was measured by using standard conductivity bridge.

All the calibration curves for different chemicals were obtained by preparing standard solutions using grade chemicals. These calibration curves were periodically repeated to check accuracy. The concentrations of different chemical components were obtained with reference to the blank solution. The analytical errors were nominal and vary within $\pm 10\%$.

IV. RESULTS AND DISCUSSION

1. Chemical Composition of Rain Water

The average seasonal concentrations, in mg L^{-1} , of major ionic components along with pH and conductivity values in $\mu\text{S (Siemens) cm}^{-1}$ are given in Table 1 for 4 monsoon seasons (1979–1982) at Baramati, Ranjangaon, Sirur, Daund, Supa and for 3 monsoon seasons (1980–1982) at Jamgaon and Wadgaon.

Table 1. The Average Seasonal Concentration (mg L^{-1}) of Major Ionic Components along with pH and Conductivity ($\mu\text{S cm}^{-1}$) at Different Stations

Stations	No. of Samples	Cl^-	SO_4^{2-}	NO_3^-	NH_4^+	Na^+	K^+	Ca^{++}	Mg^{++}	pH	Conductivity
Baramati	116	2.48	1.60	2.36	0.28	2.30	1.42	3.92	0.77	6.6	58.4
Sirur	99	2.64	1.53	2.64	0.07	1.84	0.95	3.53	0.80	6.7	49.2
Ranjangaon	107	2.02	1.53	1.37	0.08	1.81	1.41	3.30	0.96	6.8	41.7
Daund	93	1.80	1.15	3.76	0.23	1.36	1.21	4.84	0.84	6.4	49.6
Supa	66	1.51	0.62	2.15	0.05	1.08	1.45	4.84	1.05	6.9	61.5
Jamgaon	41	2.11	1.59	2.70	0.06	1.67	1.47	3.84	1.26	6.4	38.9
Wadgaon	45	1.12	0.88	0.70	0.08	0.93	0.44	2.63	0.62	6.8	39.2

(1) Variation in Cl^- and Na^+

The average seasonal concentration of Cl^- was minimum (1.12 mg L^{-1}) at Wadgaon and maximum (2.64 mg L^{-1}) at Sirur. Also, the average seasonal concentration of Na^+ was minimum (0.93 mg L^{-1}) at Wadgaon. But the maximum concentration of Na^+ (2.30 mg L^{-1}) was found at Baramati instead of Sirur. The concentrations of Cl^- and Na^+ were, by and large, maximum at all these stations during July and August, when the normal activity of monsoon is at its peak and minimum during the month of September, withdrawal period of monsoon. The high concentration of Na^+ and Cl^- in rain water during active monsoon season shows the role of sea salt in warm rain process. The higher concentrations of Cl^- and Na^+ are reported for the coastal stations in India (Sequeira, 1976; Maske et al., 1982; Khemani et al., 1985b).

The concentration of Na^+ is a good indicator of sea salt in precipitation. From the concentration of Na^+ and rainfall amount, the sea salt deposition values (D) were calculated in a conventional manner in kilogramme per hectare (kg ha^{-1}) from

$$D = \frac{(\text{Na}^+) \times R}{10} \times \frac{100}{30.5},$$

where (Na^+) is the weighted mean concentration of sodium (mg L^{-1}), R the seasonal cumulative rainfall (cm) and 30.5, the percent of Na^+ in sea salt.

The deposition values (D) of sea salt were calculated for the 7 stations and are given in Table 2. The deposition of sea salt varied from 8 to 26 kg ha^{-1} at the 7 stations. However, the average values at Colaba (coastal station) and Pune (inland station) were respectively 225 and 51 kg ha^{-1} . The average value of deposition of sea salt (17 kg ha^{-1}) at the 7 stations is about 13 times less than the value reported for coastal station Colaba and 3 times less than that at the inland station Pune. This feature indicates marked depletion of sea salt, which is mostly

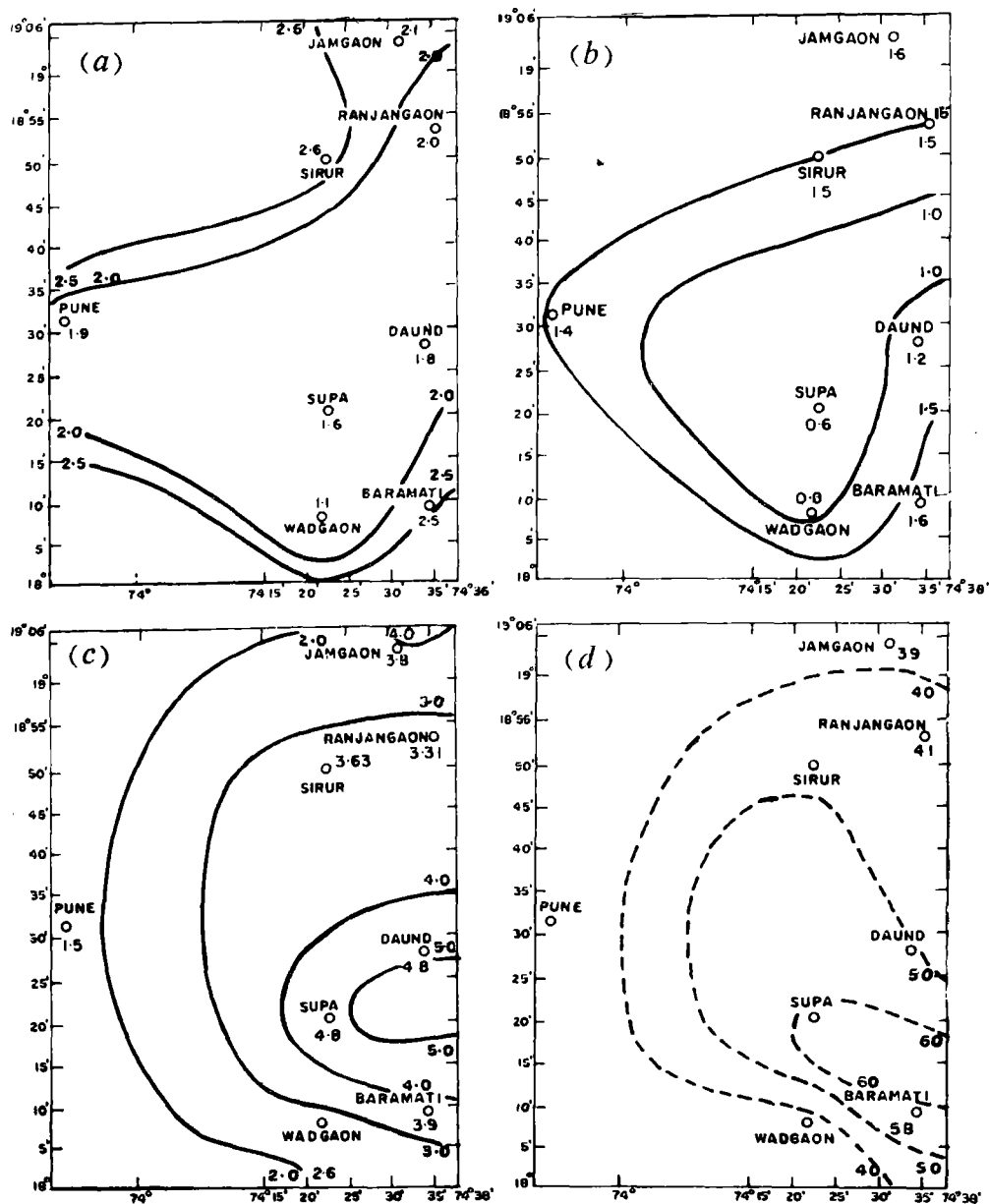


Fig. 2. Spatial variation (mg L^{-1}) of (a) chloride, (b) sulphate, (c) calcium and (d) conductivity ($\mu\text{S cm}^{-1}$).

in the giant size range of the aerosols, in the air stream as it enters the plateau (see Fig. 2a). The Cl^- has been found significantly correlated ($r \sim 0.9$) with Na^+ at all these stations and is mostly contributed by the sea which is consistent. Also, Cl^- and Na^+ are reported in the molecular form of NaCl in Pune (Khemani et al., 1982). It is therefore assumed that Cl^- does not indicate an addition of acid or base in the rain water since NaCl is a salt which is neutral.

Table 2. Average Salt Deposition in kg ha^{-1} at Different Stations

Station	Baramati	Sirur	Ranjangaon	Daund	Supa	Jamgaon	Wadgaon	Bombay.*	Pune*
Salt Deposition	26	19	25	14	8	13	14	225	51

* Sequeira and Kelkar, 1978.

(2) Variation in SO_4^{2-}

The average seasonal concentration of sulphate was minimum (0.62 mg L^{-1}) at Supa and maximum (1.60 mg L^{-1}) at Baramati. The average concentration of sulphate was 1.27 mg L^{-1} which is slightly higher than the background value (1.1 mg L^{-1}) reported in the rain water collected at 5 remote locations in the Northern and Southern Hemispheres (Galloway et al., 1982). This feature indicates that the observational sites located in the leeward side of the Western Ghats are free from industrial pollution. The low concentration of sulphate in rain water points out that pollution sources on windward side (Bombay region) of the Western Ghats are weak and localised and therefore the concentration of the pollutant (SO_4^{2-}) is diluted substantially before it is transported to the leeside of the Western Ghats. On the other hand, long-range transport of pollutant (SO_4^{2-}) was observed in the rain water over Hawaii Island transported from North American Continent which is thousands of kilometers away from the Island (Miller, 1979; Miller et al., 1981).

The excess SO_4^{2-} in rain water at all the stations was about 69% and contribution by sea was about 31%. However, this excess SO_4^{2-} does not seem to be from industrial source, since it has shown poor correlation ($r \sim 0.2$) with pH in rain water. But, it has shown significant correlation ($r \sim 0.5$) with soil-oriented elements (Ca^{++} , Mg^{++} and K^+). This observation indicates that the excess sulphate is not in the form of H_2SO_4 but in the form of calcium or magnesium sulphate. Sulphate particles in the aerosol samples in Pune region during monsoon season have shown bimodal distribution and most of the mass of sulphate was found in coarse particle size range (Khemani et al., 1982). This observation further supports that most of the sulphate in the Deccan Plateau are originating from soil. Soil has been also considered as an important source of sulphate in rain water collected in eastern territories of Hungary, where sulphate was found in coarse particle size which showed poor correlation with pH in rain samples (Horvath et al., 1984). Also, recent analysis of chemical composition of atmospheric precipitation revealed that sulphate ions were highly correlated with alkaline earth elements such as Na, K, Ca (Sequeira, 1981). These results suggest that atmospheric SO_2 may be adsorbed on particulate matter, reacting with soil-derived compounds such as CaCO_3 and Na_2CO_3 to form sulphate aerosols. Hence, it was concluded that particulate matter is very important in the mass removal of SO_2 in the atmosphere (Sequeira, 1981; Wang, 1984).

The average concentration of SO_4^{2-} (0.6 mg L^{-1}) was reported for 10 background monitoring stations in India. Except near the high industrial complexes, like Chembur in Bombay,

the concentration of SO_4^{2-} in Indian rain water is in the order of background values (Khemani, 1985).

Based on the average of 4-year data, isolines of SO_4^{2-} in mg L^{-1} are shown in Fig. 2b. An examination of Fig. 2b points out that the concentration of SO_4^{2-} is progressively decreasing eastward. This feature indicates that long-range transport of pollutants is not effective in the tropical country like India during monsoon period when the meteorological factors are favourable for quick dispersal of pollutants, also sources of pollutants are weak. Another reason for the low SO_4^{2-} concentration may be due to quick removal of pollutants by rain during monsoon seasons.

(3) Variation in NO_3^-

The average seasonal concentration of nitrate was minimum (0.70 mg L^{-1}) at Wadgaon and maximum (3.76 mg L^{-1}) at Daund. The average concentration of nitrate for 7 stations was 2.24 mg L^{-1} . However, this value is one order of magnitude more than the value (0.28 mg L^{-1}) reported in rain water collected at 5 remote locations in the Northern and Southern Hemispheres (Galloway et al., 1982).

The high concentration of NO_3^- in rain water at all the seven stations does not seem to be contributed from industrial source since the observational sites are free from industrial pollution, which is seen from the low concentration of SO_4^{2-} . Also, it showed poor correlation ($r \sim 0.1$) with pH of rain water. However, it showed good correlation ($r \sim 0.50$) with soil-oriented elements (Ca^{++} , K^+ , Mg^{++} and Na^+). This feature indicates that the nitrate is not in the form of nitric acid but in the form of salts like potassium or sodium nitrate. High concentrations of NO_3^- were reported from the 10 background stations in India where it varied from 0.1 to 3.9 mg L^{-1} . Presence of excess nitrate is not going to affect the pH.

(4) Variation in NH_4^+

The average seasonal concentration of ammonium was minimum (0.05 mg L^{-1}) at Supa and maximum (0.28 mg L^{-1}) at Baramati. The concentration of ammonium was significantly higher at Baramati (0.28 mg L^{-1}) and at Daund (0.23 mg L^{-1}) than the average concentration at all the five stations, namely, Sirur, Ranjangaon, Supa, Jamgaon and Wadgaon (0.07 mg L^{-1}). It may be noted that the first two stations (Baramati and Daund) are more populated than the other five stations. The average concentration of ammonium at these seven stations was 0.12 mg L^{-1} which is about twice the average concentration reported at 5 remote locations in the Northern and Southern Hemispheres (Galloway et al., 1982).

The average concentration of ammonium was 0.32 mg L^{-1} in the rain water samples collected for a period of one decade from 1974 to 1983 at Pune (Khemani et al., 1985b). The concentrations at coastal stations Alibag and Colaba were 0.27 and 0.50 mg L^{-1} respectively. However, the concentration at Chembur, near fertilizer factory, was 2.1 mg L^{-1} (Sequeira, 1976). The average concentration of ammonium was 0.28 mg L^{-1} in rain water samples collected during four monsoon seasons at Delhi (Kapoor et al., 1972). However, average ammonium concentration in rain water samples varied between 0.03 and 0.86 mg L^{-1} at selected locations in North America and Scandinavian countries (Munger, 1982).

Ammonium in precipitation emanates from the action of bacteria on nitrogen compounds in the soil, perhaps mainly from urine (Healy et al., 1970). It is also released from the industrial plants manufacturing fertilizers. The presence of ammonium in rain water is favourable

for neutralizing the acidic effects due to the presence of SO_4^- in the form of H_2SO_4 . Ammonium in rain water samples showed poor correlation with all the ionic components. It is commonly a component of the aged SO_4^- and NO_3^- aerosol and its weak correlation, as noticed above, with other ions would be due to the predominance of non-anthropogenic sources (Munger, 1982).

(5) Variation in K^+ , Ca^{++} and Mg^{++}

The concentration of potassium was minimum (0.44 mg L^{-1}) at Wadgaon and maximum (1.47 mg L^{-1}) at Jamgaon. The average concentration at all these stations was 1.19 mg L^{-1} .

The concentration of calcium was minimum (2.63 mg L^{-1}) at Wadgaon and maximum (4.84 mg L^{-1}) at Daund and Supa. The average concentration at all these stations was 3.84 mg L^{-1} .

The concentration of magnesium was minimum (0.62 mg L^{-1}) at Wadgaon and maximum (1.26 mg L^{-1}) at Jamgaon. The average concentration at all these stations was 0.9 mg L^{-1} .

The average concentrations reported for K^+ , Ca^{++} and Mg^{++} were respectively 0.13, 0.14 and 0.33 mg L^{-1} in rain water samples collected at 5 remote locations in the Northern and Southern Hemispheres (Galloway et al., 1982). Hence, the average concentrations of K^+ , Ca^{++} and Mg^{++} in the rain water samples relating to the present study, were higher by about 9, 27 and 3 times respectively than the values reported for the background stations of the world.

The average concentrations of K^+ , Ca^{++} and Mg^{++} for other cities in India respectively varied from 0.22 to 4.21; 0.2 to 5.55; and 0.37 to 0.67 mg L^{-1} (Sequeira, 1976; Maske et al., 1982; Khemani et al., 1985b). However, the average values reported in rain water for K^+ , Ca^{++} and Mg^{++} varied between 0.07 and 0.23 mg L^{-1} ; 0.10 and 1.15 mg L^{-1} and 0.04 and 0.48 mg L^{-1} respectively at the selected locations in North America and Scandinavian countries (Munger, 1982). The high concentrations of soil-oriented elements (K^+ , Ca^{++} and Mg^{++}) in rain water is due to high level of total suspended particulates mainly caused by dusty soil in India (Khemani et al., 1985a). Hence, during monsoon period these aerosols are incorporated in rain water due to rainout and washout processes. These elements (K^+ , Ca^{++} and Mg^{++}) are potentially basic in nature and their presence in high concentration in rain water is helpful to neutralize the acidic effects of anthropogenic emissions (SO_4^- and NO_3^-) and maintain the pH of rain water in alkaline range. Low concentration of these elements in rain water reported from western countries is the major cause of acid rain (Khemani et al., 1985b). In order to confirm the contribution of Ca^{++} from soil, the isolines of Ca^{++} concentration are plotted in Fig. 2c. The figure indicates that the concentration of Ca^{++} increases with increase in distance from the sea. Therefore the high concentration of Ca^{++} over the land confirms the contribution of soil.

(6) Specific conductivity

The average specific conductivity in $\mu\text{S cm}^{-1}$ in all the rain water samples is given in Table 1. Conductivity was maximum ($62 \mu\text{S cm}^{-1}$) at Supa and minimum ($39 \mu\text{S cm}^{-1}$) at Jamgaon and Wadgaon. The average value of the conductivity at all the stations was $48 \mu\text{S cm}^{-1}$.

Out of all the ionic components, conductivity was significantly correlated ($r \sim 0.90$) with soil-oriented elements (Ca^{++} , K^+ and Mg^{++}). This observation indicates that soil-oriented

elements, which are potentially basic in nature, are the main cause for high conductivity in rain water. This feature is also noticed from the isolines of conductivity shown in Fig. 2d. Increase of conductivity eastward could be noticed from the figure. The isolines of Ca^{++} concentration (Fig. 2c) have also shown the same tendency.

Horvath and Meszaros (1984) found the high conductivity in rain water samples due to dissolution of coarse soil particles in the rain water. They also showed an increase in specific conductivity towards inland stations. The specific conductivity was reported around $10 \mu\text{S cm}^{-1}$ in the rain water samples collected at 5 remote background stations in the world (Galloway, et al., 1982). This value of conductivity was low and occasionally approached to the conductivity of deionized water ($1.0 \mu\text{S cm}^{-1}$) in the rain water at all the 5 remote stations of the world. However, the average specific conductivity values in the rain water samples reported at 10 background stations in India range $7\text{--}57 \mu\text{S cm}^{-1}$ (IMD, 1982). The minimum specific conductivity ($7 \mu\text{S cm}^{-1}$) has been reported at Kodaikanal, a hilly station which is relatively free from soil dusts due to its altitude. However, the highest conductivity ($57 \mu\text{S cm}^{-1}$) has been reported at Jodhpur where the rainfall is influenced by the dissolution of soil dusts available from the nearby Rajasthan desert.

2. pH of Rain Water

The average pH value in rain water at the seven stations varied from 6.4 to 6.9. Hence, rain water samples are alkaline in nature over this region.

The pH values of rain water collected at all these stations have shown significant correlation with Ca^{++} ($r \sim 0.6$), K^+ ($r \sim 0.5$) and Mg^{++} ($r \sim 0.48$). This feature points out that the soil-oriented elements have a significant influence on pH of rain water. The influence of soil particulates on pH of rain water can be clearly seen from the chemical analysis of rain water samples collected at Retz, a semi-arid region in Austria. The high concentration of Ca^{++} (6.06 mg L^{-1}) in rain water during 1978 neutralised the H ion concentration to some extent and increased the pH up to 5.4 which is very near to the critical value of rain acidity (Cehak et al., 1985). Rain water at Retz, like India, could have been in the alkaline range, but high concentration of SO_4^{--} ($\sim 17 \text{ mg L}^{-1}$) transported from the industrial sources in Europe overpowered the natural source and maintained the pH towards the acidic range.

Theoretically, none of the pH values measured on rainfall should exceed 5.6 if the dissolution of atmospheric CO_2 , NO_x and SO_x gases in rain water is the main control over acidity. The values higher than 5.6 indicate that precipitation is reacting with other atmospheric constituents which have the capacity to neutralize acidity. The most likely factors include inorganic components of airborne dust. It has been suggested that alkaline dust may react with and neutralize strong acids in the atmosphere (Khemani, 1985). Naturally-derived particles from soil erosion, agricultural activity, constructional sites, unpaved roads, and volcanoes may play an important role in determining the acidity of precipitation. This has been seen in agricultural areas of central and mid-western United States where dust emission from carbaceous soils with high calcite and dolomite content acts as a buffers (Smith et al., 1970). In addition, there is a significant amount of data scattered throughout the literatures listing pH values above 5.6 which reflect the possible neutralizing effect of airborne dust (Applin et al., 1986).

V. CONCLUSION

Chemical characteristics of rain water over the rural areas situated on the leeward side of

the Deccan Plateau have shown that a significant amount of dust is incorporated into rain water either as condensation nuclei or by coalescence with falling rain drops. It is apparent that the incorporation of dust with wet precipitation can neutralize the acidity and enhance the pH values of rain water. However, the extent to which these reactions occur may be largely dependent upon both the composition and concentration of suspended dust particulates within a geographic region. Available data suggest that rain water in urban and rural as well as in so-called background stations in India will remain alkaline, so long as the airborne dust particles continue to remain alkaline.

REFERENCES

- Applin, K.R. and Jersak, J.M. (1986), Effects of airborne particulate matter on the acidity of precipitation in central Missouri, *Atmos. Environ.*, **20**:965—969.
- Cehak, K. and Chalupa, K. (1985), Observations of various chemical contaminants of the precipitation at a Bapmon station in the eastern Pre-Alpine region. *Arch. Met. Geophys. Biocl.*, Ser. B, **35**:307—322.
- Das, D.K., Dev Burman, G.K. and Kidwai A.L. (1981), Chemical composition of monsoon rain water over Bhopal, Madhya Pradesh (India) during 1977 and 1978, *Mausam*, **32**:221—228.
- Galloway, J.N., Likens, G.E., Keene, W.C. and Miller, J.M. (1982), The chemical composition of precipitation in remote areas of the world, *J. Geophys. Res.*, **87**:8771—8786.
- Handa, B.K. (1969), Chemical composition of monsoon rain over Calcutta, Pt. 1 and Pt. 2, *Tellus*, **21**:95—106.
- Handa, B.K. (1973), Chemical composition of monsoon rains over Chandigarh in 1971, *Indian Geohydro.*, **9**:31—37.
- Handa, B.K., Kumar, A. and Goel, D.K. (1982), Chemical composition of rain water over Lucknow in 1980, *Mausam*, **33**:485—488.
- Healy, T.V., McKay, H.A.C., Pilbeam, A. and Scargill, D. (1970), Ammonia and ammonium sulphate in the troposphere over the United Kingdom, *J. Geophys. Res.*, **75**:2317—2321.
- Horvath, L. and Meszaros, E. (1984), The composition and acidity of precipitation in Hungary, *Atmos. Environ.*, **18**: 1633—1645.
- IMD (India Meteorological Department), (1982), Atmospheric turbidity and precipitation chemistry data from background air pollution monitoring network stations in India (1973—1980); II—10 to 12.
- Kapoor, R.K., Khemani, L.T. and Ramana Murty, Bh. V. (1972), Chemical composition of rain water and rain characteristics at Delhi, II, *Tellus*, **24**:575—580.
- Khemani, L.T. and Ramana Murty Bh.V. (1968), Chemical composition of rain water and rain characteristics at Delhi, *Tellus*, **20**:283—292.
- Khemani, L.T., Momin, G.A., Naik, M.S., Murty, A.S.R. and Ramana Murty, Bh. V. (1982a), Variation in ionic composition of rain water during twelve consecutive summer seasons (1969—1980), Proc. of the conference on cloud physics, held at Chicago, pp. 68—69.
- Khemani, L.T., Momin, G.A., Naik, M.S., Vijayakumar, R. and Ramana Murty, Bh. V. (1982b), Chemical composition and size distribution of atmospheric aerosols over the Deccan Plateau, India, *Tellus*, **34**: 151—158.
- Khemani, L.T. (1985), Characteristics of atmospheric gaseous and particulate pollutants and their influence on cloud microphysics and rain-formation, Ph.D. thesis, University of Poona, Poona.
- Khemani, L.T., Naik, M.S., Momin, G.A., Kumar, R., Chatterjee, R.N. and Ramana Murty, Bh.V. (1985a), Trace elements in the atmospheric aerosols at Delhi, north, India, *J. Atmos. Chem.*, **2**:273—285.
- Khemani, L.T., Momin, G.A., Naik, M.S., Prakasa Rao, P.S., Kumar, R. and Ramana Murty, Bh.V. (1985b), Impact of alkaline particulates on pH of rain water in India, *Water, Air, Soil Pollution*, **24**:365—376.
- Mahadevan, T.N., Meenakshy, V. and Sathe, A.P. (1984), Some observations on the chemical composition of precipitation in an industrial area and its use in air quality assessment, *Mausam*, **35**:87—90.
- Maske, S.J. and Krishna Nand (1982), Studies on chemical constituents of precipitation over India, *Mausam*, **2**:241—246.
- Miller, J.M. (1979), The acidity of Hawaii precipitation as evidence of long range transport of pollutants, World Meteorological Organization, Sofia, Bulgaria, Oct. 1—5.
- Miller, J.M. and Touhinoga, A.N. (1981), The acidity of Hawaiian precipitation, a preliminary report, *Geophys. Res. letter*, **8**:779—782.

- Mukherjee, A.K. (1957), Hydrogen ion concentration of monsoon rain water at Calcutta, *India J. Meteor. Geophys.*, **8**:321—324.
- Mukherjee, A.K. (1964), Acidity of monsoon rain water, *India J. of Meteor. Geophys.*, **5**:267—270.
- Munger, J.W. (1982), Chemistry of atmospheric precipitation in the north-central United States: Influence of sulphate, nitrate, ammonia and calcareous soil particulates, *Atmos. Environ.*, **16**:1633—1645.
- NEERI (National Environmental Engineering Research Institute), (1980), Air Quality in selected cities in India, 1978—1979.
- Rao, Y.P. (1976), Meteorological monograph, Synoptic Meteorology, No. 1/1976, South west monsoon, IMD: 2—27.
- Sequeira, R. (1976), Monsoonal deposition of sea salt and air pollutants over Bombay, *Tellus*, **28**:275—281.
- Sequeira, R. (1981), Acid rain: Some preliminary result from global data analysis, *Geophys. Res. letter*, **8**:147—150.
- Smith, R.M., Twiss, P.C., Krauss, R.K. and Brown, M.J. (1970), Dust deposition in relation to site, season and climatic variables. *Proc. Sci. Soc. Am.*, **34**:112—117.
- Subramanian, V. and Saxena, K.K. (1980), Chemistry of monsoon rain water at Delhi, *Tellus*, **32**:558—561.
- Wang Mingxing (1984), Chloride deficit and the non-acid rain in Beijing, *Advances in Atmospheric Sciences*, **1**: 81—88.