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Analyzing rainwater chemistry at the continental GAW station Nagpur

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सार – इस शोध पत्र में 1981 से 1996 तक की अवधि में नागपुर में हुई वर्षा के पानी में रासायनिक तत्वों की उपलब्धता का अध्ययन किया गया है। इस अध्ययन से यह पता चला है कि नागपुर में वर्षा ऋतु में बार–बार गर्ज के साथ आने वाले तूफानों के कारण वर्षा के पानी में Na^+ और Cl^- के सांद्रणों में समुद्र का प्रभाव कम है। यहाँ पर मानसून ऋतु के आगमन से पहले के महीनों में और पूरी मानसून ऋतु के दौरान NO_3^- में बहुत अधिक सांद्रता रिकॉर्ड की गई है। मानसून ऋतु के दौरान K^+ को छोड़कर वर्षा के पानी के सभी घटकों की अगस्त तक सांद्रता कम होती जाती है। तथापि, सितंबर में सभी घटकों की सांद्रता में वृद्धि पाई गई है। Cl^- और Na^+ के निक्षेपण मान तटीय केंद्रों की तुलना में काफी कम पाए गए हैं। SO_4^{-2} के निक्षेपण मानों की तुलना यू. एस. एस. आर. के कुछ भागों में पाए गए मानों से की जा सकती है। वर्षा के पानी के विभिन्न घटकों के बीच अनुपातों का अध्ययन करने और समुद्र के पानी के अनुपातों के साथ उनकी तुलना करने से पता चला है कि नागपुर में वर्षा के पानी में Na^+ की अधिकता का कारण समुद्र के पानी के अलावा अन्य स्रोत भी हैं। pH मानों में बहुत अधिक विभिन्नता पाई गई है। मानसून में, जून के ,बाद pH कम होता जाता है और सितंबर तक बहुत कम हो जाता है। इसका कारण वर्षा के पानी द्वारा मूल कैटायनों का पृथक करना माना जा सकता है। अप्रैल और मई के सबसे तेज गर्मी के महीनों में pH की अधिक मात्रा का कारण वातावरण में धूल कणों की मात्रा, जिसमें मुख्यतः मूल कैटायन होते हैं, को माना जा सकता है। मानसून ऋतु के प्रत्येक माह के pH के अध्ययन से पता चला है कि जून और जुलाई में वर्षा का स्वरूप सर्वाधिक मौलिक है जबकि अगस्त और सितंबर में नागपुर में अम्लीय वर्षा की कुछ घटनाएँ देखी गई हैं। जब मार्च और दिसबंर के दो महीनों में pH का मान 5.0 से नीचे गिर जाता है तब अम्लीय वर्षा की समस्या बहुत अधिक विकट होती है। मानसून पूर्व ऋतु के दौरान उच्च संचालकता मानों का कारण इस अवधि में वातावरण में धूल कणों की अधिक सांद्रता को माना जा सकता है। घटकों और वर्षा के बीच $Y = AR^{-B}$ के रूप में विपरीत संबंध पाया गया है।

ABSTRACT. In this paper rainwater chemistry of Nagpur for the period 1981-1996, has been studied. The analysis reveals that at Nagpur rain water there is less marine influence on the concentrations of Na^+ and Cl^-. Pre-monsoon months, as well as the season as a whole, record higher NO_3^- concentration which could be attributed to frequent thunderstorm activities in this season. During monsoon months, concentration of all the constituents of rainwater, except K^+, goes on decreasing till August. However, in September increase in concentration is observed for all the constituents. Deposition values of Cl^- and Na^+ are found to be quite low in comparison to that at coastal stations. SO_4^{-2} deposition value is comparable to the values reported in some parts of USSR. Study of ratios between various constituents and a comparison with sea water ratios reveals that rainwater at Nagpur gets enriched in terms of Na^+ from other sources besides sea water. pH values exhibited large variation. In monsoon, June onwards pH goes on decreasing and lowest value is obtained in September. This could be attributed to the preferential removal of basic cations by rainwater. In the peak summer of April and May higher values of pH could be attributed to the abundant prevalence of dust particles in the atmosphere chiefly consisting of basic cations. pH of individual months of monsoon season reveals that in June and July rainfall is predominantly basic in nature while in August and September some instances of acid rain has been observed at Nagpur. Acid rain problem seems to be more acute in the month of March and December when pH in these two months falls below 5.0. High conductivity values during pre-monsoon season could be attributed to higher dust concentrations in the atmosphere during this period. An inverse relationship of form $Y = AR^{-B}$ has been found between the constituents and rainfall.

Key words – Rain water chemistry, Acid rain, Deposition value, Marine influence.

1. Introduction

Urbanization, industrial expansion and changes in land use pattern modify, though in long term perspective, weather and climate. Economic activities of man are capable of affecting the heat balance of the earth and its atmosphere which in turn modify weather and climate at regional and global scales. In addition, different kinds of pollutants are continuously released into the atmosphere through the human activities; rainfall returns these pollutants to the earth where they can affect biological processes in terrestrial and aquatic ecosystems. Study of chemical composition of rainwater thus, provides information regarding the status of air pollution as well as helps in gaining significant knowledge for many geo-chemical investigations, water supply for human consumption, agriculture etc.

The investigations of chemical composition of rainwater began a long time ago. However, only since last 2-3 decades they have been widely used in connection with various scientific and applied problems. Recently, the investigation of rainwater composition has attracted attention because of the problem of growing air pollution.

Rainwater is one of the chief weathering agents and its chemical composition provides significant knowledge for many geo-chemical investigations, water supply for human consumption, agriculture and above all for monitoring environmental pollution; besides, it also gives an indication of the gaseous and particulate composition of a large depth of atmosphere that traversed by raindrops falling from clouds in the atmosphere. Falling through the atmosphere, the rainwater carries some major, minor and trace elements, externally present in the atmosphere. The rainwater also dissolves some gaseous compounds in the atmosphere, which are normally released during combustion of fossil fuels. Similarly storms containing dust and other foreign particles may constitute 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 in the rainwater. The composition of rainwater is affected by both, cloud microphysical and the sub-cloud layer pollutant composition. Thus, rainwater samples from different shower events, exhibit variable compositions. But when monthly mixed samples of rainwater are chemically analyzed and the net depositions are accounted for over a substantial length of time, it is mainly the ambient atmospheric burden of pollution that gets reflected while the weather related factors only cause the variations about the mean values.

Although considerable study on rainwater chemistry has been done in Europe, USA, Australia and other foreign countries (Eriksson 1958, 1960; Emanuelsson *et al.* 1954; Egner and Eriksson, 1955; Carroll, 1962) yet in India studies on this aspect are still meagre. In India, under the aegis of the WMO, a network of 10 Background Air Pollution Monitoring (BAPMoN), presently GAW (Global Atmospheric Watch) stations has been established. In Vidarbha region, Nagpur had been selected as the only BAPMoN, hereafter, GAW station. In India though some studies have been conducted on chemical composition of rainwater (Das, 1988, Maske and Krishna Nand, 1982; Mukherjee *et al.*, 1986, Mukhopadhyay *et al.*, 1992, Mukhopadhyay *et al.*, 1993) yet no detailed study is available on various aspects of chemical composition of rainwater at Nagpur over Vidarbha region. In view of this the present study is aimed at analyzing precipitation chemistry data from the only available GAW station in Vidarbha region *i.e.*, Nagpur for the period 1981-1996. Following aspects have been investigated: (*i*) Seasonal variation of pH and other chemical constituents, (*ii*) Wet deposition rate of different chemical constituents, (*iii*) Linear regression of chemical constituents of rainwater with rainfall amount and (*iv*) Sources of chemical constituents.

2. Methodology

A wet-only sampling program was undertaken at the station under the India Meteorological Department, using manually operated stainless steel collectors. Samples were filtered through Whatman-41 filter papers immediately after collection to remove any particulate matter. The pH and Electrical Conductivity (EC) were measured and then the samples were transferred to polythene storage tank. Chemical analysis was done at the Central Laboratory at Pune on monthly mixed samples for the ions, *viz*., SO_4^{-2}, NO_3^-, NH_4^+, Ca^{+2}, Mg^{+2}, Na^+, and K^+. The pH values were measured with a digital pH meter using reference (KCl) and glass electrodes, standardized with pH of 4.0 and 9.2 reference buffers before pH determination. Conductivity was measured according to standard methods using a conductivity bridge standardized with 0.01N KCl solution. The concentrations of SO_4^{-2}, NO_3^-, NH_4^+ and Cl^- were determined using colorimetric methods , SO_4^{-2} was determined by Barium iodate method (Klockow and Ronicke, 1973) and NO_3^- was determined by Brucine sulphate method (Jenkins and Medsken, 1964). The concentration of Cl^- was determined by mercuric thiocyanate method (Florence and Farrar, 1971) and that of NH_4^+ was determined by Berthelate colour-reaction procedure (Weatherburn, 1967). The concentrations of Na^+, K^+, Ca^{+2} and Mg^{+2} were determined by Atomic Absorption Spectrophotometer with air-acetylene flame and instrument settings recommended by the instrument manufacturer. Automiser times and voltage setting for each metal followed recommendation of the manual. All

TABLE 1

Monthly mean concentrations of various constituents of rain water

Month	Rainfall (mm)	SO_4	NO_3	Cl	NH_4	Ca	Mg	Na	K
		(mg/litre)							
		1.46	8.25	0.54	0.55	4.51	0.54	0.78	0.66
Feb	27.5	1.51	7.87	0.84	0.73	1.65	0.82	0.59	0.49
Mar	50.2	2.24	22.52	0.77	0.74	2.28	0.34	0.67	1.03
Apr	16.8	2.67	14.22	0.86	0.22	8.12	4.52	3.20	1.36
May	28.1	0.63	15.19	0.88	0.18	3.98	1.29	1.33	0.84
Jun	158.1	1.18	4.97	0.96	0.30	1.40	0.64	1.03	0.32
Jul	326.1	0.72	4.64	0.88	0.23	1.28	0.31	0.78	0.42
Aug	274.9	0.53	3.06	0.46	0.21	0.90	0.13	0.39	0.70
Sep	171.1	0.90	4.73	0.50	0.12	1.05	0.49	0.55	0.99
Oct	81.9	0.90	7.16	0.50	0.15	1.49	0.17	0.47	0.57
Nov	24.0	1.13	5.18	0.53	0.00	2.04	0.50	0.96	1.64
Dec	27.0	2.19	6.75	0.69	0.38	6.19	0.93	0.73	1.26

TABLE 2

Seasonal mean concentrations of various constituents of rain water

Season	Rainfall (mm)	SO_4	NO_3	Cl	NH_4	Ca	Mg	Na	K
		(mg/litre)							
Winter	88.1	1.72	7.62	0.69	0.55	4.12	0.76	0.70	0.80
Pre-monsoon	95.1	1.84	17.31	0.84	0.38	4.79	2.05	1.73	1.08
Monsoon	930.3	0.83	4.35	0.70	0.21	1.16	0.39	0.69	0.61
Post-monsoon	105.9	1.01	6.17	0.51	0.08	1.76	0.33	0.72	1.10

the averages used in this study are precipitation volume weighted means; this includes averages of pH also which have been computed from the corresponding H^+ ion concentrations.

Deposition rate of the different constituents (SO_4^{-2}, Na^+, Cl^-, Ca^{+2}, Mg^{+2}, Na^+ and K^+) have been computed by multiplying the concentration of the respective constituents with rainfall amount and expressed as kg/ha.

3. Results and discussions

3.1. *Monthly and seasonal concentrations*

Monthly and seasonal concentrations of various constituents of rainwater at Nagpur are presented in Tables 1 and 2 respectively. Monthly concentrations are graphically presented in Fig. 1.

Data in Table 1 reveal that SO_4^{-2} concentrations are the highest (2.67 mg/litre) in the pre-monsoon month of April; March and December also have comparable values of 2.24 and 2.19 mg/litre. NO_3^- concentrations have been found to be high in the pre-monsoon months with the highest (22.52 mg/litre) occurred in the month of March; this could be attributed to the higher thunderstorm activities in this season. In the case of Cl^- and Na^+, highest concentrations have been found in June and April respectively. With the progress of the monsoon, concentrations of Cl^- and Na^+ in rainwater decreases gradually except in September which indicates that there is relatively less marine influence on the concentrations of Cl^- and Na^+ at Nagpur rainwater. In the case of Ca^{+2} and Mg^{+2} highest concentrations have been observed in April and that of K^+ in the month of December. During monsoon months, the concentrations of Ca^{+2} and Mg^{+2} in rainwater follow the pattern of Na^+ and Cl^-; whereas that

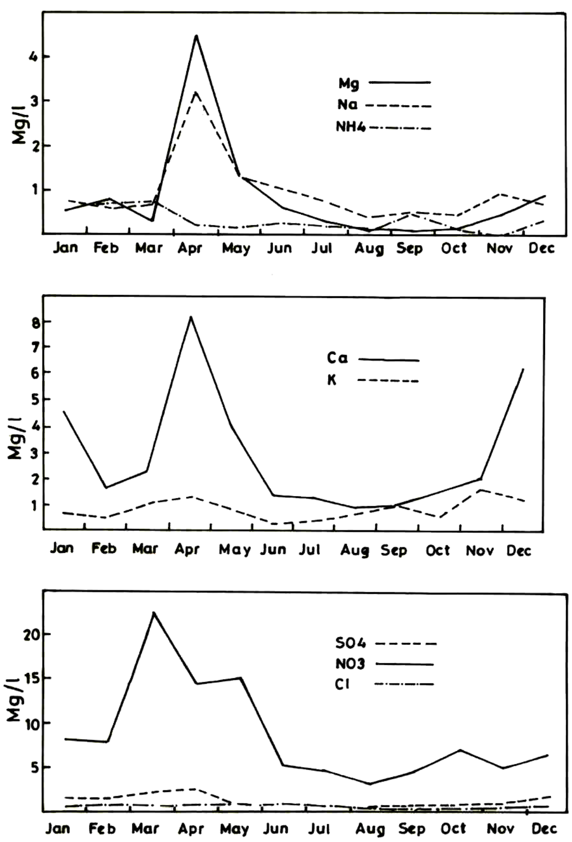

Fig. 1. Monthly concentration (mg/litre) of various constituents of rain water at Nagpur

of K^+ increases as the monsoon season progresses. NH_4^+ concentrations showed a slightly different pattern *i.e.*, its concentration during monsoon months gradually decreases from June onwards and attains lowest value in September. Values are comparatively higher during January to March.

In order to find out seasonal variation, seasonal means were computed and the same are presented in the Table 2. Data therein reveal that except Cl^-, NH_4^+ and Mg^{+2} all the other chemical constituents, attain lowest values during the monsoon season, whereas, except NH_4^+ and K^+, all the other constituents attain their highest concentrations during pre-monsoon season. Very high NO_3^- concentration (17.31mg/litre) in pre-monsoon, as stated earlier, could be due to more number of thunderstorm activities in this season. It may be mentioned here that at Nagpur during monsoon season average rainy days are much higher, 47.8 days out of 122 days; these figures for the winter, pre-monsoon and post monsoon seasons are 2.9 out of 90 days, 4.1 out of 92 days and 3.5 out of 61 days respectively. So, except for local source, monsoon rainwater analysis is the most reliable.

Since, rainwater can contribute significantly to the nutrient requirement of plants, studies regarding the deposition of various constituents is of importance from agricultural point of view. Keeping this in view, yearly deposition values of the different constituents (SO_4^{-2}, NH_4^+, Cl^-, NO_3^-, Ca^{+2}, Mg^{+2}, Na^+ and K^+) have been computed and presented in Table 3. Average SO_4^{-2} deposition value (9.5 kg/ha) is comparable to the values reported by Eriksson (1952) from some parts of USSR (7 – 8 kg/ha). Cl^- and Na^+ deposition values, 7.5 and 7.6 kg/ha respectively, are quite low in comparison to that for coastal stations. Sequeira (1976) had estimated the Na^+ deposition value of 54 kg/ha at Bombay. For Ceylon, Cl^- deposition was reported to be 200 kg/ha (Eriksson 1952). However, Na^+ and Cl^- deposition values at Nagpur are comparable to that in Pune (10.5 and 8.3 kg/ha respectively) as observed by Mukherjee *et al*., 1985. Deposition values of NO_3^-, NH_4^+, Ca^{+2}, Mg^{+2} and K^+ have been found to be 58.3, 2.6, 15.9, 4.5 and 6.9 kg/ha respectively with considerable amount of inter annual fluctuations.

3.2. *Ratios of chemical constituents*

In order to assess the marine influence on the concentrations of various chemical constituents it is the practice to calculate the ratio of various chemical constituents with reference to Na^+ or Cl^-. However, Na^+ would be better reference than Cl^- (Sequeira, 1976) during monsoon since atmospheric particles and cloud condensation nuclei can lose considerable amount of their original Cl^- due to change in phase and separation in space. Besides, Cl compounds can also occur in gaseous (HCl) and other industrial compounds (Sequeira, 1973).

Weight ratios of various constituents are calculated and their values are given in Table 4. The results reveal that in all the months of the year, as well as in all the seasons, (Winter, Pre-monsoon, Monsoon and Post-monsoon) Cl^- to Na^+ ratios are quite low than that in sea water (1.8) indicating that either loss in Cl^- has taken place or for Na^+ there are other sources also besides sea water. In winter (December - February) Cl^- to Na^+ ratio is 0.98; December - January of this season records very low values of 0.55 and 0.69 respectively, whereas in February the value is comparatively higher (1.41). During pre-monsoon season, in March the value of Cl^- to Na^+ ratio is 1.14 which is much higher than the values in April (0.27) and May (0.66); this could be due to increase in Na^+ concentration in the environment from continental sources caused by the intense convective activities usually taking place in these months. During monsoon season in July

TABLE 3

Deposition values (kg/ha) of different constituents of rain water

Year	SO_4^{-2}	NO_3^-	Cl^-	NH_4^+	Ca^{+2}	Mg^{+2}	Na^+	K^+
1981	4.31	14.59	4.00	1.42				
1982	3.23	17.05	4.88	0.97				
1983	1.52	4.80	4.95	2.92				
1984	4.87	8.99	3.69	1.66				
1985	9.59	40.38	10.80	0.01				
1986	6.59	25.83	4.26	1.14	12.63	19.11	15.37	1.35
1987	6.58	35.46	10.60	0.57	18.05	0.47	14.62	4.14
1988	8.06	27.56	9.46	2.08	4.34	6.77	8.35	4.25
1989	8.14	28.08	4.56	2.28	1.69	1.55	4.20	3.38
1990	7.99	54.34	7.54	3.29	27.97	2.24	4.38	4.81
1991	6.01	27.01	6.14	0.01	13.72	2.26	2.67	3.89
1992	4.02	43.28	9.32	0.21	17.68	0.93	2.71	25.53
1993	9.73	279.52	8.13	1.78	21.76	0.90	5.60	6.83
1994	7.65	156.92	12.03	13.33	22.22	7.96	11.03	4.89
1995	53.82	114.62	8.85	8.56	14.41	2.56	5.31	7.18
1996	10.09	54.60	10.63	1.31	20.40	4.75	9.93	9.35
Average	9.55	58.31	7.49	2.60	15.90	4.50	7.65	6.87
SD	11.68	68.80	2.75	3.39	7.39	5.18	4.34	6.24
CV	122.35	117.98	36.76	130.69	46.51	115.15	56.65	90.83

TABLE 4

Ratio of various chemical constituents of rain water

Month/Season	Cl/Na	SO_4/Na	Mg/Na	Ca/Na	K/Na
Jan	0.69	1.87	0.69	5.76	0.84
Feb	1.41	2.54	1.38	2.77	0.82
Mar	1.14	3.32	0.50	3.38	1.53
Apr	0.27	0.83	1.41	2.54	0.43
May	0.66	0.47	0.97	3.00	0.63
Jun	0.93	1.14	0.62	1.36	0.31
Jul	1.12	0.91	0.39	1.63	0.53
Aug	1.16	1.35	0.32	2.30	1.78
Sep	0.92	1.65	0.90	1.93	1.81
Oct	1.06	1.90	0.35	3.15	1.20
Nov	1.06	1.18	0.52	2.12	1.70
Dec	0.55	3.00	1.28	8.51	1.73
Winter	0.98	2.45	1.09	5.86	1.14
Pre-monsoon	0.46	1.02	1.18	2.76	0.62
Monsoon	1.01	1.21	0.57	1.68	0.88
Post-monsoon	0.73	1.44	0.46	2.46	1.54
Sea water	1.8	0.25	0.12	0.04	0.04

TABLE 5

Mean annual and monsoon pH for different years at Nagpur rain water

Year	pH	
	Annual	Monsoon
1981	6.08	6.12
1982	6.75	6.73
1983	6.31	6.30
1984	6.58	6.55
1985	5.71	7.06
1986	5.50	6.40
1987	5.71	6.91
1988	5.44	5.40
1989	4.88	5.10
1990	5.36	5.79
1991	6.81	6.80
1992	6.74	6.76
1993	4.67	4.70
1994	5.76	5.95
1995	5.31	5.93
1996	5.83	6.01

and August, this ratio is comparatively higher than that in June and September; the reason could be the higher Cl^- concentration of marine origin during July and August which are the active monsoon months at Nagpur. In all the months high ratios of SO_4^{-2}, Mg^{+2}, Ca^{+2} and K^+ with Na^+ in comparison to sea water indicates that besides marine sources there are other continental sources for these elements.

3.3. *pH and conductivity*

pH is an indicator of the intensity of acidity or alkalinity and measures the concentration of hydrogen ion in water. pH scale ranges from 0-14 with 7 as neutral. Usually lower than 7.0 pH value refers to acidic solutions while higher than 7.0 value refers to basic ones, but for natural rainwater, in equilibrium with atmospheric CO_2, pH is 5.7; therefore, rainwater having pH values less than 5.7 is considered as acid rain.

Conductivity of rainwater gives an idea about the total dissolved solids contained in water. Conductance of water increases with increase in the concentration of dissolved substance.

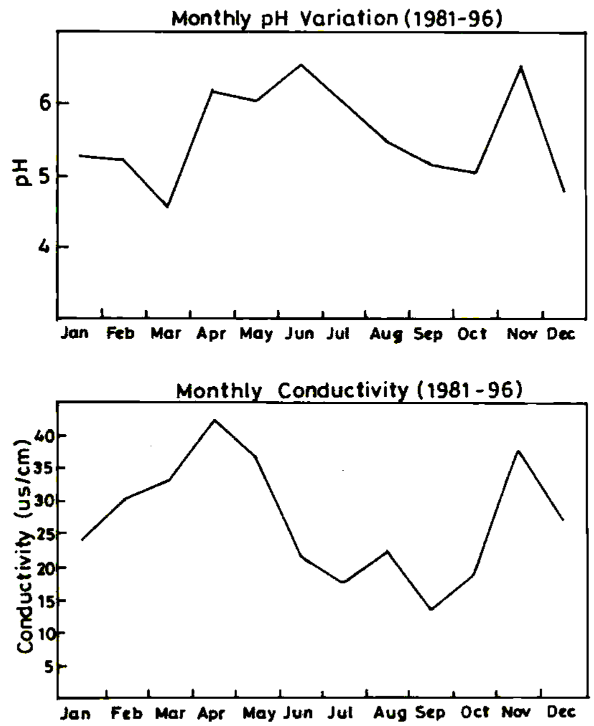

Fig. 2. Monthly variation of pH and conductivity of rain water at Nagpur

Annual and monsoon season mean pH for individual years are shown in Table 5. Data therein reveal that out of 16 years, mean annual pH values have been found to be less than 5.7 *i.e.*, acidic in 6 years and rest 10 years are basic; for monsoon season, these figures are 3 and 13 years respectively.

pH values for the individual monsoon months of June to September as well as that in March and December for different years have been presented in Table 6. A deeper look into the data reveals that June rain water is invariably basic in character; in July 1988 and 1989 acid rain occurred, in other years July rainfall was basic; in August and September though rainfall weighted mean (RWM) shows acidic nature yet a deeper look reveals that in August out of 16 cases only in 1988, 1989, 1990 and 1993 acid rain occurred, in other years August rainwater was basic in nature; similarly in September also despite acidic RWM acid rain occurred only in 1989, 1990, 1993, 1995 and 1996. pH characteristics of March and December rainwater are discussed in the next paragraph.

Monthly mean values of pH and conductivity have been presented in Table 7 and graphically shown in the Fig. 2. Data therein reveal that over Nagpur out of 12 months in 7 months, namely, January, February,

TABLE 6

pH values for the individual monsoon months(June to September) and March and December for different years

Year	pH					
	Monsoon months					
	June	July	August	September	March	December
1981	6.1	NA	5.9	6.4	5.5	NR
1982	6.7	6.9	6.8	6.5	NR	NR
1983	6.5	6.4	6.0	6.8	6.8	6.3
1984	6.9	6.4	6.6	7.2	NR	NR
1985	7.3	7.6	6.7	7.3	NR	6.9
1986	6.7	6.6	6.8	5.8	NR	4.6
1987	6.8	6.8	7.0	7.0	6.2	6.6
1988	6.7	5.1	5.1	6.6	5.5	NR
1989	6.6	5.2	4.8	5.3	4.2	4.9
1990	6.1	6.5	5.6	5.3	4.6	4.7
1991	6.8	6.9	6.7	NA	NR	NR
1992	6.9	6.9	6.6	6.9	6.7	NR
1993	6.9	6.2	4.5	4.3	4.4	6.3
1994	6.3	5.8	6.1	6.1	NR	NR
1995	7.1	6.7	6.0	5.4	4.5	NR
1996	7.1	6.5	6.0	5.6	NR	NR
RWM	6.5	5.9	5.5	5.1	4.6	4.8

NA= Not available
NR= No rainfall

March, August, September, October and December the rainwater is acidic in nature *i.e.*, pH less than 5.7. The degree of acidity is comparatively high in March and December when pH values in these months falls below 5.0. This led to have a detailed look at the pH values of these two months, besides monsoon months, which have been presented in the Table 6. The data therein reveal that in March out of 16 years (1981-1996), in 9 years rain occurred and out of these 9 years in 6 years rainwater was acidic in nature and in December rain occurred in 7 years, out of which in 4 years rainwater was basic and in the remaining 3 years it was acidic in nature. Further, it can be observed (Table 7) that the pH values are comparatively higher in April, May and June and again in November. Sudden increase in pH in April, May and June in comparison to that in March could be attributed to the abundant prevalence of dust particles during this period in the atmosphere which chiefly consist of basic cations and thus increases the pH significantly. From June onwards as the monsoon season progresses the pH also goes on

TABLE 7

Monthly mean pH and conductivity of rain water

Month	Rainfall (mm)	pH	Conductivity (Us/cm)
Jan	33.6	5.28	24.22
Feb	27.5	5.21	30.55
Mar	50.2	4.58	33.24
Apr	16.8	6.15	42.25
May	28.1	6.01	36.43
Jun	158.1	6.52	21.10
Jul	326.1	5.99	17.38
Aug	274.9	5.47	22.02
Sep	171.1	5.15	13.12
Oct	81.9	5.04	18.51
Nov	24.0	6.49	37.35
Dec	27.0	4.76	26.88

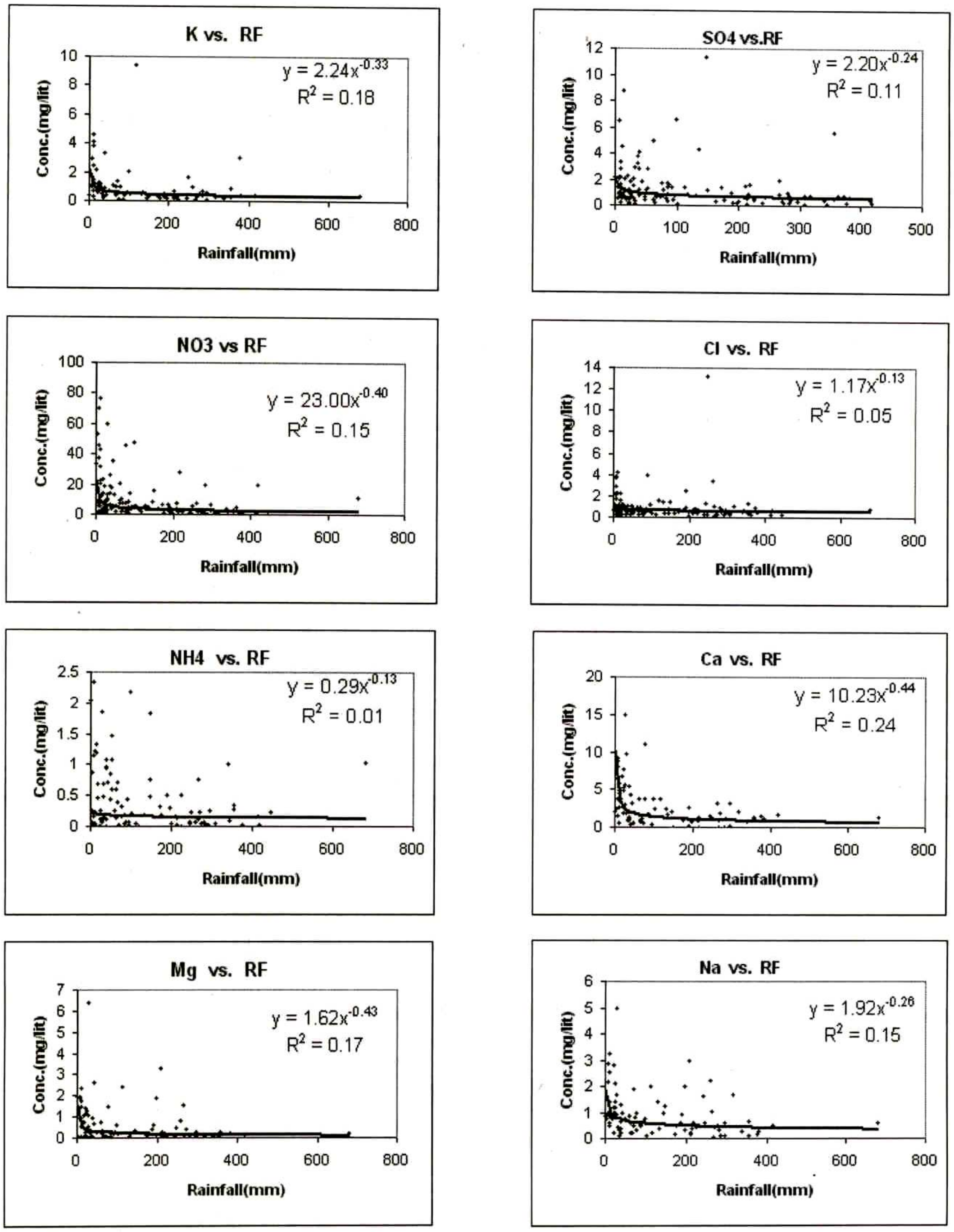

Fig. 3. Variation in concentration of constituents with rainfall amount

decreasing and the lowest pH during monsoon season is attained in September. The June-onward decrease in pH could be attributed to the preferential removal of basic cations by rainwater from the atmosphere.

Conductivity values are high during pre-monsoon months of March, April and May and the highest value is obtained in April. Higher values in pre-monsoon months are attributed to the higher dust concentrations in the atmosphere during this period. The values are comparatively low during the monsoon months of June to September.

3.4. *Variation of concentration of chemical constituents with rainfall*

The chemical composition of rainwater reaching ground level is governed by various physical processes, such as formation and growth of rain drops, rainout and washout of the pollutants and on the inter-gap between low rainfall events. Concentration generally varies inversely with the amount of rainfall. Inverse relationship was attributed to droplet evaporation, amount of liquid water content in cloud and the contribution of a wash out (Junge, 1963). Mukherjee (1980) also showed that there is an inbuilt inverse relationship of concentration of washed out material with the intensity of rainfall. The variation in concentration of different chemical constituents with rainfall amount is shown in Fig. 3. The data in this figure (Fig. 3) can be fitted by a curve of the form $Y = \mathrm{A}R^{-\mathrm{B}}$ where Y is the concentration of different chemical constituents in mg lit^{-1}, A and B are constants and R is the rainfall (mm). The curve of the form of $Y = \mathrm{A}R^{-\mathrm{B}}$ gives a better fit than straight line curve of the form of $Y = \mathrm{M}x + \mathrm{C}$. It shows that initially with slight increase in rainfall amount concentration falls exponentially, after that the fall is much more gradual and follows a straight line curve. Mukherjee *et al*. (1985) also could fit concentration of different chemical constituents at Pune with rainfall amount with $Y = \mathrm{A}R^{-\mathrm{B}}$ form of curve.

4. Conclusions

Based on the study of rainwater chemistry data of Nagpur for the period 1981-1996, following conclusions can be drawn:

(*i*) At Nagpur rain water there is less marine influence on the concentrations of Na^+ and Cl^-.

(*ii*) During pre-monsoon months as well as the season as a whole, NO_3^- concentration is very high which could be attributed to more frequent thunderstorm activities in this season.

(*iii*) During monsoon months of June to September, concentration of all the constituents of rainwater, except K^+, goes on decreasing till August. However, in September increase in concentration is observed for all the constituents.

(*iv*) Deposition values of Cl^- and Na^+ are found to be quite low in comparison to that at coastal stations. SO_4^{-2} deposition value is comparable to the values reported in some parts of USSR.

(*v*) Study of ratios between various constituents and a comparison with sea water ratios suggest that rainwater at Nagpur gets enriched in terms of Na^+ from other sources besides sea water.

(*vi*) pH values exhibited large variation. In monsoon, June onwards pH goes on decreasing and lowest value is obtained in September. This could be attributed to the preferential removal of basic cations by rainwater. In the peak summer of April and May higher values of pH could be attributed to the abundant prevalence of dust particles in the atmosphere chiefly consisting of basic cations.

(*vii*) pH of individual months of monsoon season reveals that in June and July rainfall is predominantly basic in nature. In August and September some instances of acid rain has been observed over the region.

(*viii*) Acid rain problem seems to be more acute in the month of March and December when pH in these two months fall below 5.0.

(*ix*) High conductivity values during pre-monsoon season could be attributed to higher dust concentrations in the atmosphere during this period.

(*x*) An inverse relation of form $Y = \mathrm{A}R^{-\mathrm{B}}$ has been found between the constituents and rainwater.

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