Rainwater quality from 1983 to 2005 and during pre-monsoon and post-monsoon periods in Visakhapatnam, India: a measure of industrial development

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Abstract Rainwater quality has become an increasing environmental concern for developing nations. The contributions of industrial operations, embedded into various components of the hydrological cycle, affect water quality. A study on the time series of rainwater quality from Visakhapatnam, located on the east coast of India, has revealed the impact of atmospheric pollutants originating from industry. Industrial growth effects on rainwater quality were evaluated. An important observation is that rainwater salinity is higher in the pre-monsoon months of February, March, April, May and June than in the monsoon and post-monsoon months of July, August, September, October, November and December. Electrical conductivity of rainwater increased from 1983 to 2005 and pH decreased. Furthermore, trends in Cl^-, SO_4^{2-}, NO_3^-, NH_4^+, and Ca^{2+} concentrations and the concentration ratio of $SO_4^{2-} + NO_3^-$ to $NH_4^+ + Ca^{2+}$ reflect the increasing threat of acidic atmospheric deposition in the region.

Key words monsoon; industrial operations; aerosols; precipitation scavenging; wash-out; acid rain; India

INTRODUCTION

Rainwater scavenges aerosols and gases in the atmosphere. Chemical analysis of bulk precipitation helps to reveal the ionic composition of the air in which the rain-bearing clouds were formed (Heiz & Erisman, 1995). The dust from land-based anthropogenic activity is transported by wind into the atmosphere. Population growth, increased automobile traffic and industrialization produce large emissions of SO_x and NO_x (Banerjee, 2008), which when scavenged by rainwater or "washed out" of the atmosphere increase rainwater acidity. Rainwater acidity has steadily increased in many parts of the world (Medha *et al*., 2002) during the last half-century, with progressive industrialization.

Acid rain is a major environmental concern world-wide. The term "acid rain" refers to rain with a pH ≤ 5, which is the pH of water in the absence of acidifying substances other than CO_2. Acid rain is caused by air pollution, mainly the combustion of fossil fuels. The oxides of sulphur and nitrogen are emitted by fossil fuel combustion, i.e. burning of natural gas, oil, coal and firewood (Maske & Krishnanand, 1982). Acid rain inhibits plant growth, discolours and deteriorates buildings and other major structures, and affects the life cycles of micro-organisms. Many studies have reported the hazardous nature of acid rain throughout the world (e.g. Postma, 1970).

PRESENT WORK

The research presented herein is an analysis of rainwater solution from the industrial zone of Visakhapatnam. The city is studded with major industries such as Hindustan Zinc Limited (HZL), Coromandel Fertilizers Limited (CFL), Visakhapatnam Port Trust (VPT), Hindustan Petroleum Corporation Limited (HPCL), Bharat Heavy Plates and Vessels (BHPV), Hindustan Polymers Limited (HPL), Steel Plant (SP), Coastal Chemicals (CC), Andhra Cement Company (ACC) and Simhadri Thermal Power Corporation (STPC). The industrial development, initiated after 1950, triggered a "population explosion" in Visakhapatnam; the population increased from 0.6 million inhabitants in 1983 to 2.2 million inhabitants in 2003.

About 200 ancillary industries were developed to supplement the main industries, cited above, which turned the central basin of Visakhapatnam into an air-polluting chimney (Subbarao &

Subbarao, 1996). The atmospheric aerosol content is highest during the "dry" periods, which results in a high ionic content due to precipitation scavenging. Marine aerosols also add to the industrial "contribution". Visakhapatnam, thus, is subject to heavy air pollution, when compared to inland stations such as Pune, Jodhpur, Kodaikanal and the Port Blair island station.

The city is surrounded by hills on three sides (Kailasa and Kambala konda hills on the north; Narava and Nadupuru hills on the west; Yarada hills on the south) and the Bay of Bengal on the east (Fig. 1). Thus, emissions and aerosols are shielded from the wind by mountains on three sides, only allowing coastal spray (marine aerosols) from the east.

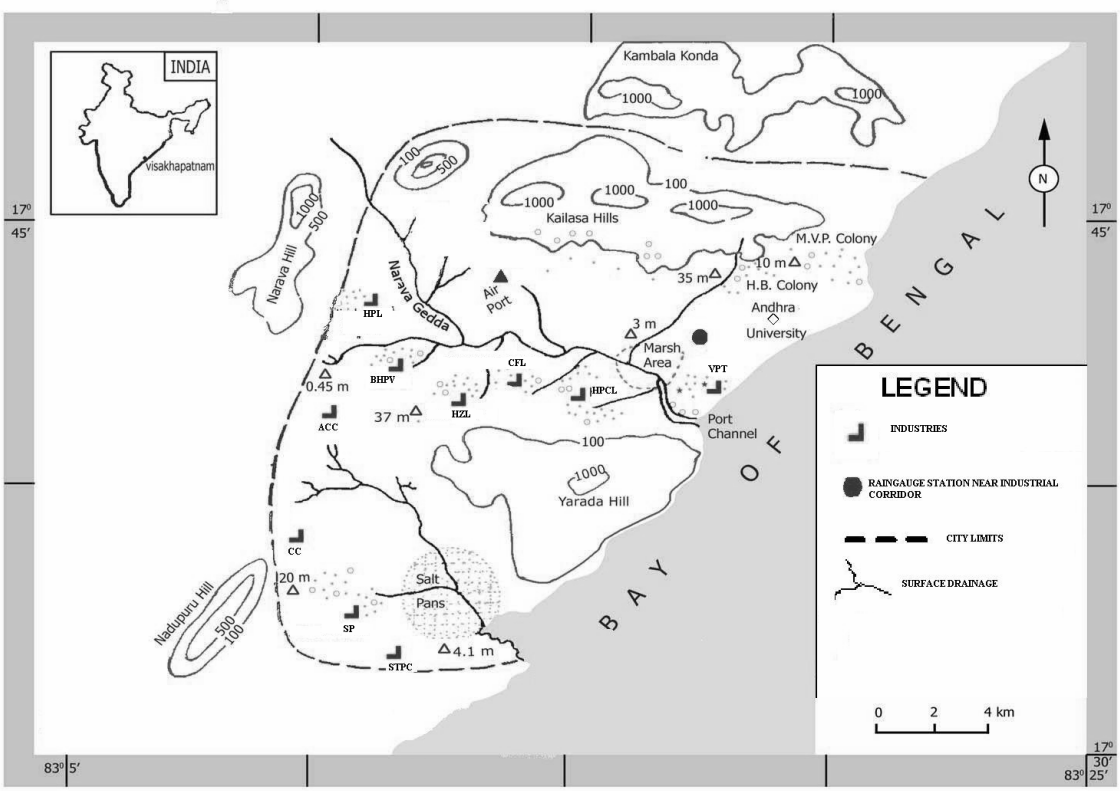

Fig. 1 Location of major Industries in Visakhapatnam.

Combustion emits large quantities of chemicals from industries such as zinc, fertilizer (nitrogen, phosphate and potassium), polymers, cement, steel production and HPCL. Also, studies have indicated that washout of SO_x and NO_x in rainfall were derived from automobile emissions in the city (Sarma & Subbarao, 1972).

DATA COLLECTION AND ANALYSIS

The Indian Institute of Tropical Meteorology (IITM), Pune, has conducted acid rain studies for the last three decades in various parts of the country. The research presented herein is an evaluation of the average annual pH, electrical conductivity (Ec) and major ion concentrations, including Cl^-, SO_4^{2-}, NO_3^-, NH_4^+ and Ca^{2+}, of rainwater in Visakhapatnam during 1983–2005.

The India Meteorological Department (IMD), Visakhapatnam, collects "bulk precipitation" monthly and sends the samples to IITM for chemical analysis. The monthly data on pH, Ec, along with SO_4^{2-}, NO_3^-, NH_4^+ and Ca^{2+} concentrations of bulk precipitation for the period from 1983 to 2005, were obtained from IITM, Pune. The annual average values were calculated for the 22-year period (Table 1). The concentration ratios of annual average $SO_4^{2-} + NO_3^-/NH_4^+ + Ca^{2+}$ from 1986 to 2005 are also listed in Table 1. Ratios greater than 1 indicate the dominance of acid bearing ions

Table 1 Average annual Ec and pH, and SO_4^{2-}, NO_3^-, NH_4^+, and Ca^{2+} concentrations from 1983 to 2005.

Year	pH	Ec (μs/cm)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)	NH_4^+ (mg/L)	Ca^{2+} (mg/L)	$(SO_4^{2-} + NO_3^-) / (NH_4^+ + Ca^{2+})$
1983	6.6	45	-	-	-	-	-
1984	6.4	47	-	-	-	-	-
1985	6.2	37	-	-	-	-	-
1986	6.0	47	1.5	5.7	0.3	7.7	0.9
1987	5.6	51	1.4	11.0	0.02	3.6	3.4
1988	6.4	77	1.5	5.3	0.4	2.4	2.4
1989	6.1	68	1.4	7.8	0.6	5.4	1.5
1990	5.6	75	1.5	11.5	0.8	2.6	3.8
1991	5.0	83	2.7	19.4	1.0	2.6	6.1
1992	4.7	89	1.9	26.4	0.9	2.9	7.5
1993	5.8	130	1.7	12.4	3.9	14.0	0.8
1994	5.6	120	1.9	35.3	1.3	6.9	4.5
1995	5.7	122	9.7	9.3	6.2	2.7	2.1
1996	5.2	130	4.0	5.2	0.7	1.8	3.6
1997	5.1	128	7.4	8.2	0.5	7.0	2.1
1998	4.9	141	11.1	14.6	0.3	10.6	2.3
1999	4.9	139	6.1	11.9	0.8	2.7	5.1
2000	4.3	145	8.0	17.5	1.1	3.8	5.1
2001	4.5	138	7.9	6.5	2.4	2.2	3.2
2002	5.3	146	12.3	10.9	2.7	3.7	3.6
2003	4.1	150	11.3	3.3	2.9	2.6	2.7
2004	5	159	16.8	24.9	1.0	6.0	5.9
2005	4.2	156	16.9	21.2	2.6	3.8	5.9

like NO_3^- and SO_4^{2-} over the alkaline elements, Ca^{2+} and NH_4^+. The ratios fluctuated markedly with more than 90% of them >1 and a maximum of 8, suggesting that rainfall is dominantly acidic.

MONSOON EFFECT ON RAINWATER QUALITY

It can be clearly observed from Fig. 2(a)–(c) that the accumulation of dust in the bulk collector and precipitation scavenging has been higher during the pre-monsoon period than during the monsoon (July, August and September) and post-monsoon (October, November and December) periods, when the ionic concentrations in the bulk rainfall samples are comparatively low. This suggests that rainfall during the monsoon scavenged aerosols and gases from the atmosphere.

The increase in annual average Ec with time likely reflects industrial expansion and subsequently higher pollutant emissions accompanying the expansion. Ec increased from 1983 to 2003 whereas pH decreased to quite acidic levels. The condition is likely worse for event rainfall because the bulk rainfall collector contains large dust particles, which generally can neutralize rainfall acidity after the rain is collected.

Figure 2(a)–(c) indicates that solute concentrations are highest during the pre-monsoon season, which is partly due to evaporative concentration in the collectors. However, during the post-monsoon season, the reverse situation is observed with respect to the increase of rainfall. The phenomenon of increase in concentration of Cl^-, SO_4^{2-}, NO_3^- and NH_4^+ during the pre-monsoon and decrease after the monsoon is reflected during September, October and November of 1983, December of 1993, and October and November of 2003.

DISCUSSION

Ec and pH, as represented in Table 1 and Fig. 3, indicate the "impending" disaster in the industrial atmosphere, which is more pronounced when the two variables complement each other. The

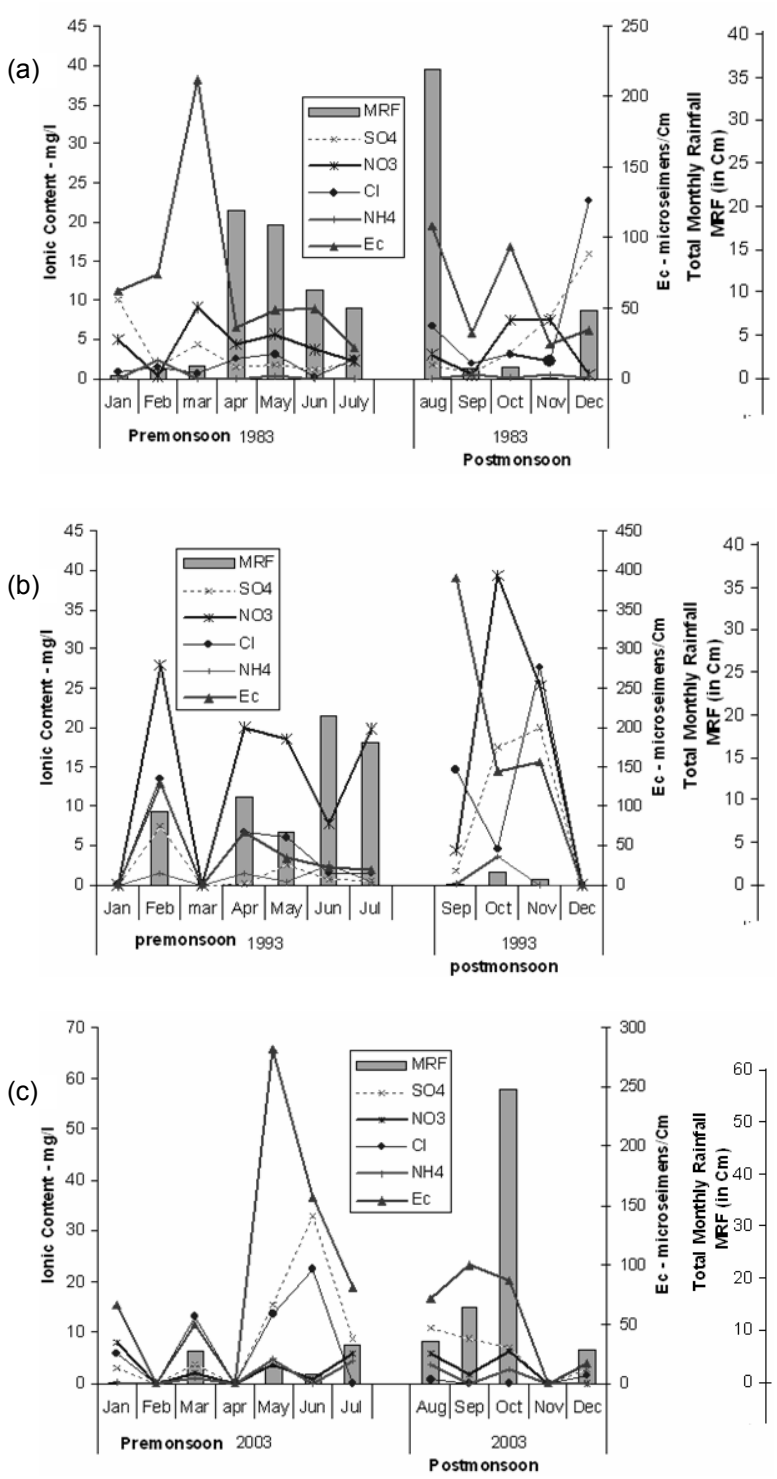

Fig. 2 Pre-monsoon and post-monsoon rainwater quality during: (a) 1983, (b) 1993, and (c) 2003. Note the changing vertical scales.

average electrical conductivity has steadily risen from a value of 45 µs/cm in 1983 to 156 µs/cm during 2005, suggesting an overall increase of particulate load. The annual average pH varies during the study period, but the general trend is of decreasing pH, i.e. from 6.6 during 1983 to 4.2 during 2005. The danger mark of acidity (pH < 4.5) is looming large on the head of the industrial sky (Linkens *et al*., 1979). This threshold deviates from the average rainwater pH of 6.5 for India

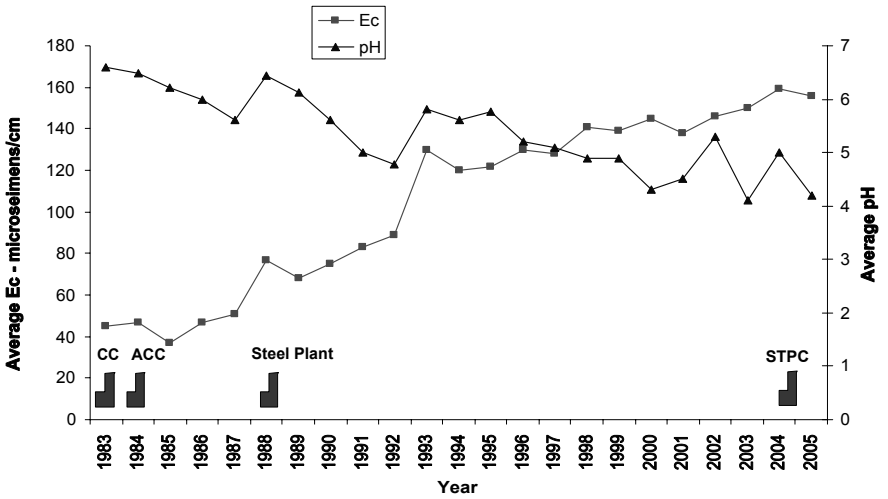

Fig. 3 Time variations of annual average Ec and pH values during the period 1983 to 2005.

(Banerjee, 2008). The pH decrease was most pronounced following the commissioning of a major industrial installation, the Steel Plant, during 1989 (Fig. 3). An international airport opened during 2009 and the change in atmospheric circulation accompanying the increased airline traffic is likely to adversely affect the atmospheric deposition.

With an areal extent of about 200 km^2, the city of Visakhapatnam is surrounded on three sides by mountains and the Bay of Bengal on the fourth, so is effectively shielded from many winds, with only marine air moving into the basin. The major industries along with the Port, like HPCL, HZL, CFL, BHPV, HPL, CC and ACC, are within a distance of 13 km from the coast. Two large industries, a Steel Plant and STPC, which are in the suburbs, have accelerated the occurrence of acid rain, as shown by the trends of Ec and pH in Fig. 3.

CONCLUSION

The average annual pH of rainwater over the industrial corridor of Visakhapatnam has become increasingly acidic (4.2 in 2005), indicating the presence of strong acidic ions in Visakhapatnam rainwaters. Ionic fluctuations are compared with the declining trend of pH and the increasing trend of Ec. The trends reflect increased solutes in rainwater likely derived from emissions from industry and urban development.

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