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Variation of rainwater quality in Visakhapatnam

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सार — विशाखापट्टनम में वर्ष 1991 से 1993 तक की तीन वर्षों की अवधि में वर्षा जल में विद्युत चालकत्व (ई सी) का अध्ययन किया गया है। कम वर्षा के समय उच्च विद्युत चालकत्व का तथा अधिक वर्षा के समय पानी में तनूकरण प्रक्रिया के कारण निम्न विद्युत चालकता का पता चला है। ग्रीष्म ऋतु के महीनों की तुलना में मानसून अवधि में ई० सी०/आर० एफ० का अनुपात घटता है क्योंकि ग्रीष्म ऋतु के दौरान एकत्र हुआ क्षारापन वर्षा के पानी के साथ बह जाता है। भारत में विशाखापट्टनम में अत्यधिक प्रदूषित औद्योगिक वातावरण के कारण अन्य स्थानों की तुलना में सर्वाधिक आयनिक अंश पाए गए। विशाखापट्टनम में, संभवत: कैल्शियम, सोडियम, पोटाशियम तथा क्लोराइड के आयनिक अंश समय के साथ-साथ बढ़ रहे हैं।

ABSTRACT. The electrical conductance (EC) of rain waters at Visakhapatnam is studied for a three year period of 1991-93. Lower amounts of rainfall (RF) record higher conductivity values and *vice-versa* due to dilution process of the amount of rain. EC/RF ratios decrease from summer months to monsoon as the accumulation of salts during dry periods is drained off with the progress of monsoon rains. Visakhapatnam records higher ionic contents than other stations in India due to highly polluted industrial atmosphere. The ionic contents for Ca, Na, K and Cl are possibly increasing with time at Visakhapatnam.

Key words — Ionic content, Dust load, Wash-out, Conductivity, Rainfall amount, Wind speed.

1. Introduction

The electrical conductivity is a well-established parameter in rainwater chemistry, indicative of the total ionic activity of the solution. It not only makes the repeated measurements easy but also helps the characterisation of water quality when individual ions behave erratically. The character of the rainwater solution, being a composite effect of many factors like coastal spray, industrially polluted air, urban lift of particles, agricultural impact and forest fires, can not be explained for separate ions as much as it could be explained in total by conductivity. Occasional analyses for separate ions would serve the specific purpose.

During the last two decades of studies, rainwater chemistry gained momentum in India, where there are varied climatic parameters and three types of rainfall summer thunderstorms (March-May), southwest monsoon (June-September) and cyclones of Bay of Bengal (October-December). The study of rainfall quality of Visakhapatnam is more interesting as it is a coastal station, studded with giant industries like Steel Plant, Bharat Heavy Plates and Vessels, Port, Hindustan Zinc Smelter, Polymers and Shipyard. Ironically, the industrial city is surrounded by hill forestry on three sides and Bay of Bengal on the eastern side.

The rainfall is collected from a 127 mm rain gauge located on the top of Geophysics building of Andhra University and the conductivities are measured in the chemical laboratory of the department with a digital conductivity meter. Except for the fractional analysis which is done immediately during the rain, the daily rainfall conductivities are measured next day each time. A few samples are analysed for chloride, calcium, sodium and potassium five times during 1993 for a comparative discussion. The conductivity studies are made for a period of three years, 1991-93, as part of a research project on 'the effect of industrial pollution of ground water in Visakhapatnam'.

2. Data and results

The daily rainfall (mm) and conductivity (micromhos/cm) data for the three years 1991, 1992 and 1993 are given in Tables 1 (a-c). The ratio of electrical-conductance (EC) to rainfall (RF) is also determined for every rainy day and given in the table. The monthly averages of EC/RF ratios are determined and shown at the end of every month. Initially, the electrical conductances are

TABLE 1 (a)

RF (mm), EC (micromhos/cm), ratios of EC/RF and monthly average values for the year 1991

Date	RF	EC	EC/RF	Date	RF	EC	EC/RF	Date	RF	EC	EC/RF
January				**July**				**October**			
1	1.4	106	76.0	1	12.5	38	3.0	3	2.5	97	38.8
2	1.4	116	82.5	2	1.2	57	47.0	4	21.0	24	2.7
3	14.4	94	108.2	7	8.5	66	7.7	5	10.6	105	9.9
15	0.2	—	—	11	78.2	13	0.2	6	24.6	92	3.7
21	39.4	85	21.7	16	1.4	21	15.0	8	6.6	88	13.3
				17	2.1	56	26.6	9	6.0	84	14.0
Monthly average			72.0	25	2.0	30	15.0	11	4.2	77	18.0
				26	19.6	33	1.7	12	33.9	55	1.6
February				27	3.0	25	8.3	13	19.4	48	2.5
	—	—	—	28	7.5	34	4.5	16	45.8	81	1.8
March				29	1.2	57	47.6	17	3.9	59	15.1
	—	—	—					27	3.6	63	17.5
				Monthly average			13.0	28	8.0	78	9.7
April				**August**				29	6.7	27	4.0
	—	—	—					30	36.3	38	1.1
				4	7.9	17	2.2				
				7	1.9	64	33.6	Monthly average			10.2
May				12	1.3	69	53.0				
30	14.00	420	30.0	22	1.0	74	74.0	**November**			
								1	28.6	117	4.2
Monthly average			30.0	Monthly average			40.7	2	44.6	42	0.9
								3	36.4	38	
June				**September**				16	13.9	15	1.1
4	10.6	126	11.9	2	4.0	76	19.0	17	3.7	12	3.2
5	20.4	136	6.7	8	7.8	86	11.0				
6	63	42	0.7	13	4.5	61	13.5	Monthly average			2.1
7	9.8	41	4.2	16	1.5	78	52.0				
8	14.5	39	2.7	18	5.4	70	12.9	**December**			
9	5.7	77	13.5	19	7.7	93	12.0		—	—	—
10	23.5	87	3.7	20	24.7	45	1.8				
11	9.7	55	5.7	21	15.6	123	7.9				
12	0.8	56	70.0	22	22.3	57	2.6				
21	4.3	63	14.0	24	8.3	101	13.0				
24	26.2	28	1.1	25	51.5	94	1.8				
30	4.8	25	5.2	27	7.8	109	14.0				
Monthly average			11.6	Monthly average			13.4				

drawn against the RF amounts and shown in Fig. 1. As can be observed from the figure, lower amounts of RF record higher conductances and *vice-versa*. The 'wash-out' of atmospheric dust is more in the initial part of the rain which results in higher salt content. As the amount of rainfall increases, atmosphere is relatively free of salts and the additional rainwater dilutes the salt content in the

TABLE 1 (b)

RF (mm), EC (micromhos/cm), ratios of EC/RF and monthly average values for the year 1992

Date	RF	EC	EC/RF
January			
	—	—	—
February			
13	1.0	77	77.0
Monthly average			77.0
March	—	—	—
April	—	—	—
May			
1	19.4	98	5.1
18	0.3	30	100.0
22	2.0	225	112.5
24	1.8	141	78.3
26	5.3	50	9.4
27	5.1	51	10.0
Monthly average			52.5
June			
15	1.1	161	151.8
16	15.9	59	3.7
18	2.0	175	87.5
21	56.0	77	1.4
22	2.3	69	30.0
Monthly average			54.9
July			
7	1.0	143	143.0
11	94.2	6	0.06
18	5.0	90	18.0
19	0.7	76	108.0
21	3.4	87	25.5
22	1.2	48	40.0
26	30.7	38	1.2
27	28.8	33	1.1
28	5.2	45	8.7
31	13.6	60	4.4
Monthly average			29.9

Date	RF	EC	EC/RF
August			
1	1.6	74	46.0
2	1.7	88	42.0
3	5.5	25	4.5
4	40.2	82	2.0
5	24.2	38	1.6
9	20.4	19	0.9
10	2.6	70	26.9
11	1.6	165	103.0
13	1.9	87	45.0
14	17.4	33	1.9
15	22.0	38	1.7
18	25.6	19	0.7
31	16.9	25	2.8
Monthly average			21.8
September			
1	26.0	50	1.9
2	12.8	30	2.3
6	9.4	120	12.7
7	23.8	20	0.8
8	6.2	80	12.9
13	16.2	110	6.8
15	0.9	150	166.0
23	1.2	210	175.0
28	0.7	322	460.0
29	3.2	153	48.0
30	21.8	30	1.4
Monthly average			80.7
October			
2	6.4	53	8.3
7	5.3	134	25.3
8	45.5	45	1.0
9	130.3	53	0.4
10	7.7	47	6.1
11	2.4	59	24.6
20	7.3	152	20.8
21	21.8	15	0.7
22	8.4	15	1.8
Monthly average			9.9

Date	RF	EC	EC/RF
November			
3	0.6	7	11.7
5	5.2	14	2.7
6	1.8	14	7.8
7	9.7	7	0.7
8	40.0	14	0.3
9	0.4	21	53.5
10	5.8	25	4.2
11	5.3	29	5.5
14	6.2	13	2.5
15	27.9	14	0.5
16	117.3	14	0.1
17	16.6	27	1.6
18	63.5	34	0.5
19	3.4	42	12.3
26	120.2	21	0.2
Monthly average			6.8
December			
	—	—	—

rain gauge, resulting in fall of conductance. However, enormous dispersion is observed for lower amounts for all the years as the initial salt concentrations vary from day-to-day at random due to weather conditions.

To observe the phenomenon more clearly EC/RF ratios (per daily rainfall) are made use of. Conductivity per unit rainfall amount will be an indicator of the seasonal character of salt accumulation in the atmosphere. The monthly

TABLE 1 (c)

RF (mm), EC (micromhos/cm), ratios of EC/RF and monthly average values for the year 1993

Date	RF	EC	EC/RF	Date	RF	EC	EC/RF	Date	RF	EC	EC/RF
January				**July**				**September**			
	—	—	—	4	8.4	54	6.3	1	42.4	5	0.1
				8	1.2	8	6.8	2	9.6	62	11.0
February				9	0.4	116	290.0	5	7.2	183	25.4
3	0.8	423	500.0	10	2.6	124	47.7	8	0.9	140	155.5
				14	2.5	103	41.2	10	5.4	78	14.4
Monthly	average		500.0	15	25.9	111	4.2	12	34.8	4	0.1
				24	1.2	379	316.0	19	1.2	75	62.4
March				25	16.1	35	2.1	21	44.7	4	0.9
	—	—	—	26	1.2	125	128.0	22	4.0	28	7.0
				29	5.7	298	52.0	24	9.2	32	3.4
April				31	4.0	399	99.0	26	13.0	7	0.5
13	3.4	450	132.0					27	3.0	129	42.9
14	85.2	244	2.9	Monthly	average		90.3	29	6.8	46	6.7
Monthly	average		67.5	**August**				Monthly	average		25.4
				4	10.3	169	16.4				
May				6	8.5	146	58.5	**October**			
10	10.8	17	1.5	10	4.7	73	77.2	6	2.0	84	42.0
15	24.4	327	13.4	19	8.2	98	11.9	7	12.2	14	1.1
19	29.9	475	23.9	23	5.9	129	21.8	8	1.6	25	15.3
26	0.7	38	54.9	27	7.8	103	14.5	9	48.0	8	0.2
27	25.8	45	1.7	31	150.4	—	—	10	37.1	10	0.2
29	1.4	28	26.2					11	1.1	—	—
				Monthly	average		33.4	12	1.6	16	10.0
Monthly	average		20.3					13	2.7	15	5.7
								14	10.0	9	0.9
June								15	0.6	20	33.3
								16	37.1	15	0.4
15	62.0	28	0.5					17	26.2	15	0.6
16	1.4	66	46.8								
17	2.5	48	19.0					Monthly	average		10.0
22	3.3	73	21.9								
25	16.7	23	1.4					**November**			
26	19.6	6	0.3					2	1.1	—	—
27	6.4	22	3.3					4	0.6	—	—
Monthly	average		13.3					**December**			
									—	—	—

average ratios of EC/RF and the mean monthly rainfall (mm) are calculated and drawn against months as shown in Fig. 2 for the three years. The figure shows that the ratios fall steadily from January to June/July, increase suddenly in the middle of southwest monsoon and decrease again during the northeast monsoon period of October-November. The character is nunique and observed for all the three years. Higher the mean monthly wind speeds (m/s), higher accumulation of salts in the atmosphere takes place resulting in an increase of conductivity ratio. This is clear for the years 1991 and 1992 when the wind speeds increase during the peak monsoon periods (wind speed data for 1993 is not available).

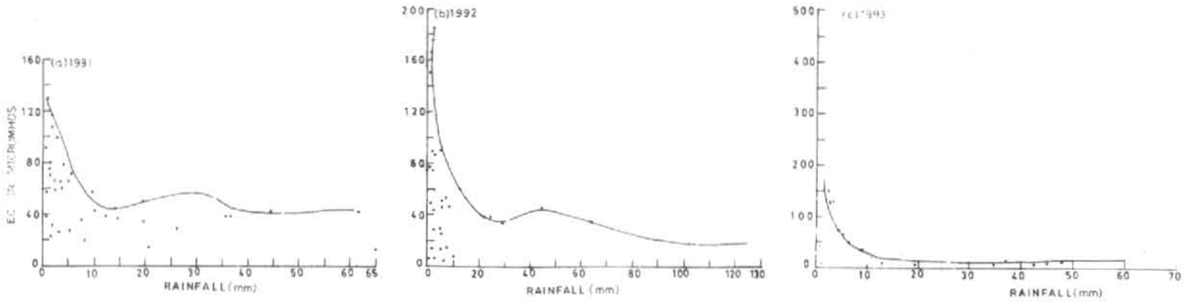

Fig. 1. Variation of EC with rainfall amount for the years 1991, 1992 and 1993

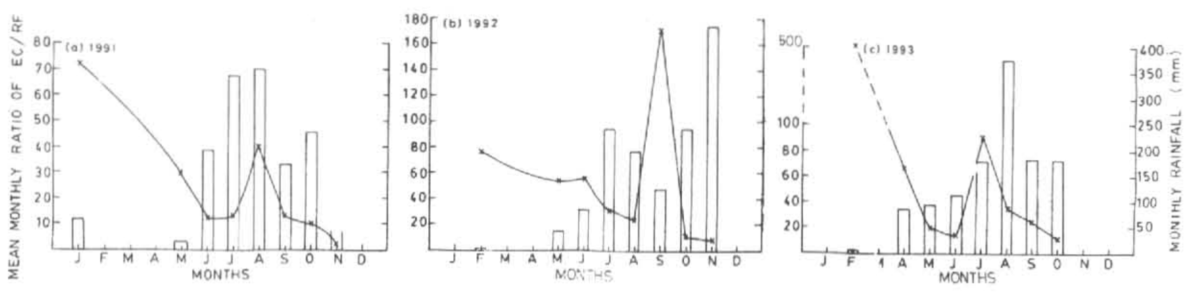

Fig. 2. Variation of mean monthly EC/RF ratio and rainfall for the years 1991, 1992 and 1993

Likens *et al.* (1979), and Leonard *et al.* (1981) among others stressed the dust load in the sky to be high during dry periods resulting in increase of ionic content in rainwater. The dust load is enormous in India during summer and for a city like Visakhapatnam coastal spray is obvious. Maske and Krishna Nand (1982) observed that Visakhapatnam is subjected to heavy air pollution when compared to other stations of India like Pune, Jodhpur, Nagpur, Mohanbari, Kodaikanal, Srinagar, Minicoy and Port Blair. The authors categorically stated that the effect of industrial air pollution is highest in Visakhapatnam and hence the 'wash-out' effect is bringing higher amounts of salts into rainwater.

As the monsoon progresses, the 'wash-out' of the summer dust is completed, but the heavy circulation of southwest monsoon winds carries salts and a new spurt in salinity can be possible during monsoon. Gorhan (1958) mentioned, in this regard, that wind velocity and daily temperatures affect the salinities of daily rainfall enormously in coastal stations. Retreat of monsoon leaves relatively salt-free rains as can be observed in Fig. 2. While this factor is observed from summer to rainy season for the three years, it can also be observed on a mini-scale during a single rain.

Fractional analysis of a continual rain is made twice during 7-8 October and 25-26 November of 1992 and shown in Fig. 3. The conductivity decreases from 110 to 20 micromhos within 24 hours of 7-8 October and in the second case falls from 50 to 10 micromhos within 24 hours (25-26 November) for a cumulative rainfall amount of around 100 mm in both cases. Fractional analysis avoids dilution in the gauge and salt content is directly related to the 'wash-out' effect at a particular segment of time. Matsuo and Friedman (1967) mentioned for

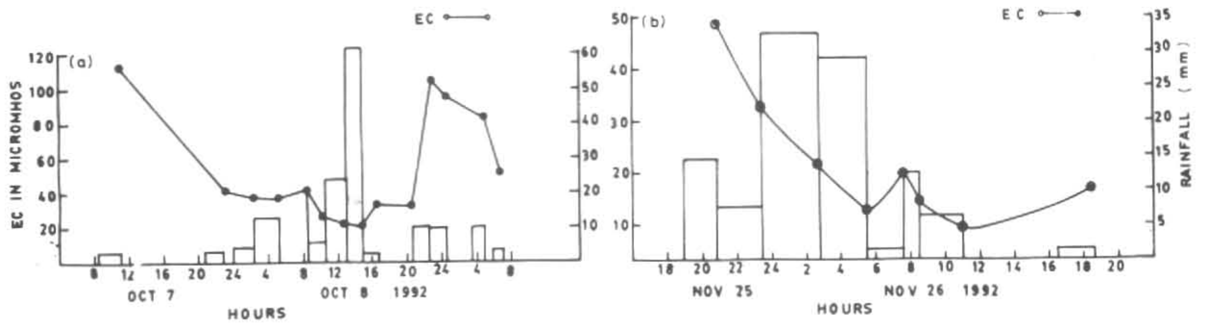

Fig. 3. Fractional analysis of conductivity of rainwater for two periods

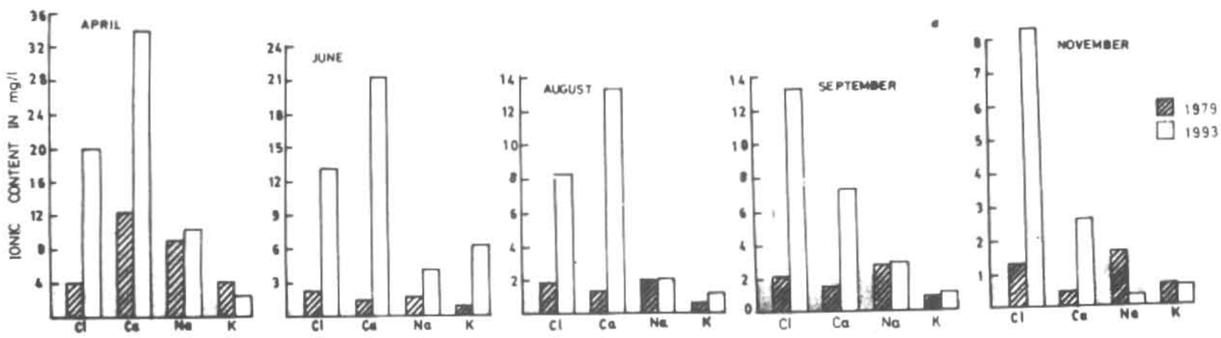

Fig. 4. Comparison of ionic content of rainwater for the years 1979 and 1993

such fractional analysis that the rate of formation of salts in the atmosphere can be clearly observed. Initial fractions recording higher conductivity and the progressive decrease of EC during the rain are observed. The salts may reaccumulate depending on wind movement also during a rain as can be observed in Fig. 3. However, there is a 'lag' of few hours for the increase of wind speed and rise in conductivity. This is possible as the reaccumulation of salts due to wind movement and their wash-out effect in conductivity can happen at the same time. Mukherjee (1960) explained a similar behaviour of conductivity for monsoon rain at Calcutta. He suggested that "in the beginning the salts are washed out of the air and hence the conductivity decreases. But a time comes when every station gets air from a zone where the rainfall has already ceased. It is the maritime air in Calcutta which contains sea salts. It is washed out by rain drops and reaccumulation starts soon. This interesting observation needs a study of more cases for a definite conclusion." Visakhapatnam, another maritime station, records similar behaviour (Fig. 3) supporting the case study of Mukherjee (1960).

2.1. *Time variation of ionic contents*

Analysis of rainwater samples for Chloride, Calcium, Sodium and Potassium ions is made for monthly samples during 1993 at Visakhapatnam. The values are compared with the data of Maske and Krishna Nand (1982) for 1979 of Visakhapatnam for the respective ions for the same periods. Both the data are given in Table 2 and represented as double bar diagram in Fig. 4.

Salinity of 1993 for all the ions has consistently been higher than 1979. While Maske and Krishna Nand (1982) had already categorised Visakhapat-

TABLE 2

Chloride (Cl), Calcium (Ca), Sodium (Na) and Potassium (K) contents of rainwater at Visakhapatnam (1979 data courtesy : Maske and Krishna Nand)

Element (mg/l)	April		June		August		September		November	
	1979	1993	1979	1993	1979	1993	1979	1993	1979	1993
Cl	4.00	20.0	2.50	13.3	1.70	8.3	2.2	13.3	1.3	8.3
Ca	12.56	34.6	1.48	21.3	1.26	13.3	1.44	7.3	0.44	2.6
Na	9.36	10.7	1.87	4.2	1.95	2.0	2.74	2.8	1.65	0.3
K	4.40	2.6	0.84	6.4	0.47	1.2	0.8	1.0	0.64	0.6
K/Na	0.47	0.24	0.44	1.51	0.24	0.6	0.29	0.35	0.38	2.0
Cl/Na	0.43	1.86	1.33	3.16	0.87	4.15	0.80	4.75	0.79	27.6

nam as a highly polluted air-zone due to industries, the explanation can be given for the increase in 1993. Industrial expansion in the city has taken place. The Hindustan Zinc Smelter was started in 1980, Cement factory in 1985, giant Steel Plant in 1987 and the Accessories of Steel Unit by 1990. The population of Visakhapatnam is doubled in the 14-year period, the vehicular traffic increased three-fold and the Port Trust expanded its export quantum with a newly constructed outer harbour with a conveyor belt in 1985 which are enough to explain the possible conditions of air salinity in the city.

Oddie (1959) and Handa *et al.* (1982) mentioned that the ratios of K/Na would indicate the difference between an inland station and a coastal station. The ratios accordingly are shown in Table 2. For a coastal station the ratios can be

$$K/Na < 1.86$$
$$Cl/Na > 1.8$$

As per the ratios of Table 2, K/Na values are less than 1.86 and Cl/Na greater than 1.8 for Visakhapatnam during all the months in a year. Handa *et al.* (1982) exactly observed the reverse in these ratios for the inland station of Lucknow. Though the sea water influence is quite evident, physiography of Visakhapatnam suggests possible influence of forests and Podu cultivation surrounding the urban limits of the city. Sarma and Subba Rao (1972) registered the behaviour of Visakhapatnam rain waters in 1970 itself wherein they mentioned that the seasonal variation of ionic activity and wind movements together determine the chemical character of rains.

3. Conclusions

(*i*) Electrical conductance per unit rainfall amount is more in summer showers and decreases with the onset of monsoon at Visakhapatnam. A sudden spurt in ionic activity is common about the end of monsoon every year.

(*ii*) The character is observed on a mini-scale during a single rain from fractional analysis.

(*iii*) The effect of industrial air pollution of Visakhapatnam is observed in rain water salinity and possibly increases with the time.

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