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PRECIPITATION STUDIES: THREE RAINY SEASONS (NOVEMBER 1989 - APRIL 1992) IN HARARE, ZIMBABWE

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ABSTRACT. The status of atmospheric pollution in Harare, the capital city of Zimbabwe is estimated by analyzing the composition of rainwater samples collected at Harare (Belvedere) for 1989-90, 1990-91 and 1991-92 rainy seasons. During the 1989-90 and 1990-91 seasons the rainfall was normal and there was drought during 1991-92 and the country experienced overall low rainfall relative to normal years. For the three consecutive rainy seasons, the composite samples of precipitation were collected on a monthly basis and the levels of the physical parameters - pH and conductance, and the chemical parameters - the concentrations of selected anions and cations, were monitored. Except for marginal differences, the magnitudes of different parameters were consistent for all the seasons. The physical and chemical parameters monitored suggest that the overall quality of the precipitation samples in the Harare region during the three rainy seasons from 1989 to 1992 was good.

INTRODUCTION

The acidification of the environment today is recognized as one of the most serious environmental problems. It is most clearly manifested in highly industrialized regions, mainly Europe and the eastern parts of North America, as a fundamental alteration of the chemical climate and as associated changes in the chemistry and biology of surface waters and terrestrial ecosystems [1]. Acid rains have been the consequential problems of anthropogenic emissions as evidenced by forest degradation in highly industrialized regions. Although there is still considerable uncertainty regarding some of the cause and effect relations, e.g. in connection with damage to forests, many environmental effects are well documented. There are very good reasons to consider acidification as one of the most serious environmental problems facing industrialized countries today. A natural question to ask is whether acidification is also a serious problem in other parts of the world. It is, therefore, extremely essential that long-term measurements are performed to document the changes that are occurring due to anthropogenic activities in the trace gas concentrations in the troposphere as these are important sensitive indicators of environmental change. The final goal is to understand our ecosystem processes and describe their sensitivity to environmental changes so accurately that we can make predictions and guide the society in handling the environmental problems. It is speculated that over the next several decades, Asia, Africa and South America will probably experience major increases in SO_2, NO_2 and HCl emissions to the atmosphere given the rate of population growth in these areas and the potential for industrial expansion [2]. Considering the global scenario, although considerable information is available about the acid rains and water acidification in industrialized regions [3-5], little is known about the atmospheric environment and the rainwater quality [6,7] in the south of the equator in Africa.

In this communication we summarize the results of our studies on the quality of precipitation over three rainy seasons of 1989-90, 1990-91 and 1991-92 at the Meteorological Service Station, Belvedere, Harare.

Normally Zimbabwe experiences four seasons, the summer (December - February), autumn (March - May), winter (June - August) and spring (September - November), and the rainy season stretches from November to April. Harare, the capital city of Zimbabwe is located at latitude 17°S and altitude 1550 m.

EXPERIMENTAL

Sampling Site: For the rainwater quality analysis, all the precipitation samples were collected at Belvedere, a suburb of Harare, where the Headquarters of the Meteorological Services Department is situated.

Sampling procedures: The precipitation samples for the 1989-90, 1990-91 and 1991-92 rainy seasons were collected by trained meteorological officers following the standard procedures. Precipitation samples of each month were pooled to make composite samples, which represented the rainwater quality for that month. The composite samples obtained were either analyzed immediately or kept in refrigerator for storage to be analyzed later for the specific physical and chemical parameters.

Methodology: For the characterization of rainwater samples, the nitrate ion was determined by the Brucine method [8], SO_4^{2-} as $BaSO_4$ by turbidimetric method [9], Cl^- by thiocyanate method [9], NH_4^+ by indophenol blue method [9], Na^+ and K^+ by flame emission spectroscopy [10].

RESULTS AND DISCUSSION

The weather system that brings rains to Zimbabwe is known as the Inter Tropical Convergence Zone (ITCZ). During the rainy season, normally from mid November to mid March, the weather system changes from a predominantly trade wind air flow to a northeasterly or northerly airflow. The high pressure regions are centered over the south Atlantic and southern Indian Oceans, allowing the warmer, more moist northerly airflow to move southwards, whilst maintaining a cool moist airflow across the country to converge with the northerlies. Moist air from the Atlantic crosses over Zaire, becoming warmer and more moist. This converges with the northeast monsoon from the equatorial region of the Indian Ocean, and is then undercut by the easterly trade winds causing the warm air to rise with convective activity as the result. 90% of Zimbabwe's rainfall is from convective activity. To maintain the activity there must be a continual supply of moist air over the tropical region. Unfortunately, there is an anomaly which develops to the southwest of Zimbabwe- the Botswana Upper High; this is an anticyclonic circulation in the middle levels which is centered over Botswana.

Once this circulation is established the airflow in the middle levels is south-easterly, subsident and dry.

During 1989-90 and 1990-91 seasons, meteorologically, Zimbabwe experienced normal rainfall (mean 662 mm) and during the 1991-92 season it received only 51% of that amount and experienced a drought situation, like many other countries in the Southern Hemisphere. The analytical data obtained for the rainy season of 1989-90 (Season I), starting from November 1989 to March 1990 are summarized in Table 1. The results obtained for the rainy seasons of 1990-91 (Season II) and 1991-92 (Season III) i.e. from November, through December, January, February and March to April are tabulated, respectively, in Tables 2 and 3. A comparison of the analytical data for the three rainy seasons suggests the magnitude of any particular parameter is fairly the same throughout the three seasons.

A perusal of the data summarized in the tables clearly indicates that the rainwater sample for April 1991 (Table 2) had maximum levels of the solutes; and had highest level of conductance (13.5 µS/cm) and also correspondingly highest levels of SO_4^{2-} (0.51 ppm), Cl^- (0.44 ppm), NO_3^- (0.051 ppm), K^+ (0.14 ppm) and Na^+ (0.40), but pH was normal (6.36) and NH_4^+ was 0.035 ppm. Further, a careful examination and comparison of the results in the three tables suggest that there is a definite increasing trend in the levels of the conductance, anions and cations from the beginning of each season to the end. Normally, rainfall is high in the beginning of the season till the middle, and the amount of rainfall decreases towards the end of the season. Thus, the lower conductance and lower concentrations of ionic species observed in the beginning of each rainy season could be to an extent, due to the dilution factor. Later in the season, the higher concentrations of ions and conductance could also be due to the accumulation of aerosols in the lower troposphere. This assumption is supported by the high conductance values observed in the terminal end of all the three seasons and low rainfall recorded during those months.

The differences in the conductivity of water samples mainly depend on the concentration of charged solutes and to a lesser extent on the nature of the solutes. Many a times, pH is not the true index of the extent or the nature of rainwater quality. The interplay of sulfates, chlorides and nitrates in a complex fashion in the troposphere after scavenged by rainfall determine the acidity of precipitation and govern the background pH. The basic aerosols from species like ammonia, however, present a buffering action rendering it difficult to characterize the background pH. As such, more base, alkaline dust, would elevate the pH, whilst more acidic aerosol particles or gas would lower it. Small variations in fluxes of acids and bases could easily cause pH variations [7].

The effect of forest fires and vegetation burning on the quality of rainwater has been clearly demonstrated in Venezuelan rains and has shown that the atmospheric budget, the concentrations of nitrate, ammonium, phosphate etc., is enhanced during the burning periods. In addition, higher concentrations of aldehydes were reported during the vegetation burning which on cloud-oxidation produce organic acid which buffer the pH of the rain water [11]. Because of the high reactivity of the tropical atmosphere during this period, the NO_x should be rapidly oxidized to produce higher levels of nitric acid. Ammonia emitted by biomass burning pay significant role in the acid-base equilibrium of the atmosphere, preventing a further acidification of rains. Nitrate, sulphate and ammonium ions must be produced in the atmosphere as final products of gaseous NO_x, SO_2, and NH_3, emitted during the burning [12, 13].

Table 1. Chemical composition of rainwater, 1989-90 season.

Month	NOV.	DEC.	JAN.	FEB.	MAR.	APR.
pH	5.30	5.41	5.45	5.75	5.85	No sample
Cond (μS/cm)	9.5	10.4	9.8	10.8	11.3	
SO_4^{2-} (ppm)	0.31	0.34	0.35	0.37	0.36	
Cl^-(ppm)	0.23	0.24	0.27	0.30	0.31	
NO_3^- (ppm)	0.032	0.036	0.034	0.036	0.041	
NH_4^+ (ppm)	0.024	0.036	0.028	0.025	0.035	
K^+ (ppm)	0.150	0.115	0.128	0.136	0.130	
Na^+ (ppm)	0.168	0.150	0.144	0.158	0.160	
No. rains	8	8	19	16	4	11
Rainfall (mm)	115	51	387	194	79	81

Table 2. Chemical composition of rainwater, 1990-91 season.

Month	NOV.	DEC.	JAN.	FEB.	MAR.	APR.
pH	5.60	6.60	6.70	6.72	6.53	6.36
Cond (μS/cm)	11.4	11.7	12.0	12.5	12.9	13.5
SO_4^{2-} (ppm)	0.41	0.43	0.44	0.46	0.48	0.51
Cl^- (ppm)	0.33	0.35	0.34	0.38	0.41	0.44
NO_3^- (ppm)	0.034	0.037	0.043	0.048	0.049	0.051
NH_4^+ (ppm)	0.026	0.029	0.033	0.035	0.037	0.035
K^+ (ppm)	0.091	0.10	0.11	0.13	0.14	0.14
Na^+ (ppm)	0.23	0.22	0.24	0.31	0.31	0.40
No. rains	7	14	15	14	13	1
Rainfall (mm)	101	161	153	156	94	6

Table 3. Chemical composition of rainwater, 1991-92 season.

Month	NOV.	DEC.	JAN	FEB	MAR	APR
pH	6.13	5.55	5.50	5.14	5.09	7.03
Cond (μS/cm)	8.5	8.8	9.9	10.3	10.5	11.5
SO_4^{2-} (ppm)	0.33	0.44	0.47	0.40	0.63	0.49
Cl^- (ppm)	0.40	0.47	0.43	0.45	0.59	0.42
NO_3^- (ppm)	0.024	0.025	0.029	0.040	0.045	0.047
NH_4^+ (ppm)	0.031	0.034	0.042	0.045	0.048	0.054
K^+ (ppm)	0.10	0.11	0.12	0.11	0.14	0.10
Na^+ (ppm)	0.14	0.15	0.12	0.27	0.13	0.13
No. rains	11	13	8	4	12	3
Rainfall (mm)	73	180	62	25	110	89

The physical and chemical details of regional acid-base and oxidation-reduction titrations are highly complex in time and space and depend, in addition to the matrix of emissions, on the different climatic, meteorologic, photochemical and geologic features of regions. Harare, with 10% of the country's population, experiences highest urban pollution due to various anthropogenic activities such as high fossil fuel consumption (automobiles), industrial activities and the 50 MW Thermal (coal) power station. Further, the sustained high levels of SO_2, HCl and NO_2 levels observed at the Industrial area and in the vicinity of the fertilizer plant [14] also suggest that industrial pollution could be the source of sulfates, chlorides and nitrates in the rainwater. Although, grassland fires and bio-mass burning also contribute to various emissions, normally grassland fires in Harare region occur during the dry months of July and August.

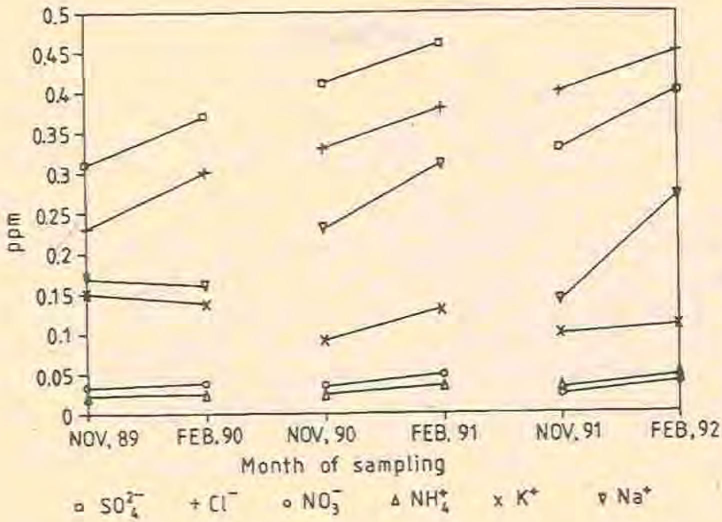

Fig. 1. Comparison of the characteristics of the precipitation samples from the three rainy seasons.

To compare the differences and similarities in the composition of precipitation, the analytical data for the November (beginning of season) and February (middle of the season) samples for all the three seasons are plotted in Figure 1. The figure clearly indicates that there is no clear trend in pH values, but in all the three sets the conductance increased from November to following February. The corresponding increases in the levels of sulphate and chloride for all three seasons and increase in the levels of sodium and potassium ions (except of 1989-90 season) explain obvious reasons for the increase in the conductance values. Furthermore, there was no distinct difference in composition of rainwater between the drought season and the normal seasons in the Harare region. This could be due to the fairly high share of rainfall (about 2/3 the normal) Harare recorded, compared to the less than 50% of annual mean experienced by the other regions.

In conclusion, the chemical and physical parameters of the precipitation samples recorded for the three consecutive rainy seasons (1989-92) suggest that the levels of pollutants are well below the desirable levels [1, 11] for aesthetic environment and comparable with the rainwater quality in clean atmosphere. The quality of atmospheric environment in Harare region of Zimbabwe is presently quite good.

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REFERENCES

1. Rodhe, H. *Ambio* **1989**, 18, 155.
2. Galloway, J.N. *Ambio* **1989**, 18, 160.
3. *Acidification of Tropical Countries, Scope 36*, H. Rodhe and R. Herrera, Eds, John Wiley & Sons: Chichester, UK; 1988.
4. Stone, A.; Seip, H.M. *Ambio* **1989**, 18, 192.
5. Crutzen, P.J. in *Scales and Global Change*, T. Rosswall, R.G. Woodmanser and P.G. Risser, Eds, John Wiley & Sons: New York; 1988.
6. Jonnalagadda, S.B.; Makhado, J. *Analytical Sciences* **1991**, 2, 5760.
7. Jonnalagadda, S.B.; Makhado, J.; Matinde, N.; Makarau, A.; Karimanzira, R.P. *The chemical composition of air and rainwater in Zimbabwe, Science of Total Environment,* Elsevier Press: Holland; 1993 (In Press).
8. Jenkins, D.; Medsker, L.L. *Anal. Chem.*, **1964**, 36(1), 610.
9. Perry, R.; Young, R.J. (Eds), *Handbook of Pollution Analysis*, Chapman and Hall: New York; 1977.
10. Dean, J.A.; Rains, T.C. (Eds), *Flame emission and atomic absorption spectroscopy, applications*, Vol.3, Mercel Dekker: New York; 1975.
11. E. Sanhueza, E.; Elbert, W.; Rondon, A.; Arias, M.C.; Hermoso, M. *Tellus* **1989**, 41 B, 170.
12. Rondon, A.; Sanhueza, E. *J. Atmos. Chemistry*, **1990**, 9, 160.
13. Crutzen, P.J. in *The geophysiology of Amazania, vegetation - climate interactions*, R.E. Dickinson, Ed., Wiley: Chichester; 1987; p 107.
14. Jonnalagadda, S.B.; Nyagani, M.; Sawunyama, P.; Baloyi, R. *Environmental International* **1991**, 17 (5), 1.