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The Spatial and Temporal Variation of pH and Lead in Rain Water in Harare City, Zimbabwe

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Abstract

Acid and lead depositions are some of the major problems facing the world today. A study was conducted in Harare, Zimbabwe's largest city, to determine the concentration and flux of lead in rainwater, and to identify areas that experience acid rain. The study was carried out during the 2000/2001 to 2003/2004 rainy seasons. Rainwater was collected after each rain event from three meteorological stations located in Harare: Harare Agricultural Research and Extension (Arex), Harare International Airport (Airport) and Belvedere. The pH and lead concentration of rainwater were determined using a pH meter and an atomic absorption spectrophotometer respectively. The results showed that Harare experienced acid rain with Arex having the highest frequency of acidic rainwater than Belvedere and Airport throughout the four seasons. Very high Pb concentration in rainwater was recorded when the rainfall amount was less than 20mm per day. The seasonal lead concentration in rainwater at all the sites was more than ten times higher than those reported in industrialised areas indicating high levels of pollution. In 2001/2002 and 2002/2003 Belvedere recorded the highest wet flux (796mg m^{-2}) while Airport recorded the least (182mg m^{-2}). Since Harare is not as industrialised as cities in the developed world, acidity and high levels of Pb in rainwater in Harare were attributed to the long range transport of pollutants and high levels of sulphur dioxide and Pb emissions from the exhausts of motor vehicles that still use leaded petrol. It was concluded that Harare experienced acid rain and Pb problem. The systematic phasing out of leaded petrol and monitoring of industrial emissions into the atmosphere could possibly reduce the problem of acidity and lead in the atmosphere especially in urban areas.

Key words: acid rain, Pb, temporal, spatial variation,

Introduction

As the world's population continues to grow fast and many countries become more industrialized than before, the ability to produce adequate food and raw materials, and at the same time maintain a healthier and good quality environment becomes a big challenge. Acid and lead (Pb) deposition, which result from gaseous and particulate emissions into the atmosphere from various industrial activities, are threatening

the quality of the environment and the ability of various nations to produce enough food and fiber today and for their future generations. Acid and Pb deposition impacts negatively on forests, soil, aquatic life and buildings and human health.

Our study has shown that Harare experienced acid and Pb deposition which are of similar magnitude or higher than that received in the developed countries despite it (Harare) having lower levels of industrialization. The significance of this study is that it shows how pollutants that are generated from outside the nation can be transported over long distances and impact negatively on the environment. This has implications on the policy-making issues at national, regional and global scales. For example the need for all nations to reduce carbon dioxide (CO_2) and the oxides of sulphur (SO_x) emissions into the atmosphere and the phasing out of leaded petrol should therefore be encouraged.

Acid rain and the presence of lead (Pb) in the environment are some of the major threats to the global environment today. Acid rain results from the reaction of carbon, nitrogen and sulphur oxides with water in the atmosphere. Wet deposition is considered the dominant removal mechanism for pollutants in the atmosphere (Baeyens *et al.*, 1990; Migon *et al*., 1991). Most of these oxides are formed from the burning of fossil fuel and industrial emissions. These gaseous emissions have been implicated in the greenhouse effect and global warming which are the major causes of negative global climatic changes such as increase in temperature, El Nino phenomenon, alteration of the hydrological cycle and environmental degradation (Weenick, 1993).

The effects of acid rain and lead on forests, soil, water bodies, biodiversity and buildings in some developed countries are well documented (Watt *et al.*, 1999; Kurczynska *et al.*, 1997; Ulrich, 1994; Matzner, 1989; Hutchnison, 1995; Eriksson, 1992; Likens *et al.*, 1996). Acid deposition may affect the fate and transport of metals as they move through the soil horizons to ground- and surface waters. The problems of acid rain cannot, however, be confined to developed and industrialised countries alone as rain clouds can be detected over large distances. Thus, remote areas far removed from industrial sources of acidifying compounds (Schnoor and Zehnder, 1996; Radojevic and Lim, 1995) can be equally affected.

Lead (Pb), a heavy metal, is a cause for concern to the environment because of its persistence and toxicity to children and the young of other animal species (Landrigan *et al.*, 1975; Needlemen *et al.*, 1982). Unlike in most western industrialised nations who started to reduce lead additives in gasoline in the 1980s (Thomas,1995), most developing countries still use petrol that contains tetramethly lead (IV) that is added as a petrol anti-knock. It is estimated that 5% of the additives are emitted uncombusted to air (Morgan and Bretthauer, 1977). About 1.5 million litres of blend are used daily by more than 95% of the vehicles in Zimbabwe (National Oil Company of Zimbabwe, 2004; personal communication). An estimated 500 000 vehicles, representing half of the vehicles in the country, are in Harare. More than 450 000 of these vehicles use blend (Central Vehicle Registry, 2003, personal communication). Prior to the

introduction of procurement of fuel by private companies in 2003 by the Zimbabwe Government, the National Oil Company of Zimbabwe (NOCZIM) was the only parastatal responsible for national fuel procurement and product quality control. Pb concentration threshold in blend imported and used in Zimbabwe is in the range 50-500 mg Pb L^{-1}. The annual average concentration of Pb in blend used in Zimbabwe since 2001 was about 170 mg Pb L^{-1} (NOCZIM, personal communication). Since the introduction of the private buyers in the fuel procurement it is anticipated that petrol with high Pb concentration will be imported into the country as there is likely to be no quality monitoring for most of these companies. This trend is likely to continue for some time.

The potential threat of Pb and rainwater pollution has been overlooked in most developing countries mainly because these nations are not highly industrialised and that there is limited documented evidence of these threats (Rhode and Herrera, 1988). The objectives of this study were to identify and monitor areas of acid rain occurrence, and to determine the Pb concentration and flux in rainwater in Harare, the industrial capital of Zimbabwe.

Methods and Materials

Site selection and location

The location of the study sites in Harare are shown in a sketch map (Figure 1). The project commenced in 2000/2001 rainy season with Harare Agricultural Research & Extension (Arex), Belvedere Meteorological Station and Harare International Airport as the recording and collecting stations. The study was terminated in 2003/2004 rainy season. All the sites were selected because they were already equipped with rain gauges. Harare was used as a case study for areas of acid rain occurrence and Pb concentration in rainwater due to its high traffic density and high industrial activities. It lies within the tropics at an average altitude of about 1470 m. It is the centre of a large agricultural zone. It contains zones of extensive light and heavy industries.

Weather pattern

The summer season for Zimbabwe starts in October but the onset of the main rains is November. This period is normally characterised by north-westerly cloudy bands that affect mostly the country's western districts. This is normally characteristic of the Congo air mass, which is the Atlantic South East Trade Air re-curving across Congo or northern Angola into the circulation of the Equatorial Low over the southern Africa sub-continent in summer. It reaches Zimbabwe from the northwest as a humid, but fairly shallow air mass. Subjected to convergence it can produce widespread rain. The Inter-Tropical Convergence Zone (ITCZ) lies across Zimbabwe in mid-summer and is bound in the northeast by the south limit of the monsoon emanating from strong continental Siberian anticyclone during the northern winter. The prevailing wind direction that affects Harare is the north-easterly (Figure 2). The rainy season is characterized by high humidity with highest temperatures of 24-32^{o}C. The annual mean rainfall is about

863 mm. The cool dry season starts from April to September. Highest temperatures of 20-26^{o}C are experienced during this period.

Rainwater and pH Analysis

Rainwater was collected in rain gauges measuring 0.127 m in diameter. Rainwater samples from the rain gauges were collected in polythene bottles on each rainy day at 0800 hrs from all the sites. These bottles were soaked in 0.1M $HN0_3$ for five days and then rinsed five times with deionised water prior to sampling. The bottles were tightly closed. After collecting the water the rain gauges were rinsed five times with deionised water. Rainwater samples were then immediately taken to the laboratory where they were analysed for pH, Ca, Mg, K, Na, Pb and conductivity. An Orion pH and conductivity meter equipped with a combined electrode was used to measure the pH and conductivity of the water. Cations contained in water were determined using an atomic absorption spectrophotometer (Buck Scientific, Model 210 VGP) after acidifying it with 2ml of 0.1M HNO_3. All analyses were on the same day, immediately after collection to avoid pH alterations. Wet Pb deposition was calculated as follows:

$$D = C \times V$$

Where D = rainwater deposition, mg m^{-2}

C = concentration of Pb in rainwater, mg l^{-1}

V = total volume of rainwater received, l m^{-2}

Seasonal wet deposition flux was calculated by multiplying the weighted average concentrations (mg l^{-1}) with the total precipitation (l m^{-2}) during the rainy season under consideration. In cases where the concentration of Pb in rainwater was below the detection limit a value of zero concentration was put instead in order to plot the graphs.

Statistical analysis

Data on pH was expressed in class ranges and represented in a frequency distribution bar graph. Rain water conductivity, basic cation and Pb concentration were tabulated as monthly means and standard error of means.

Results and Discussion

pH variability

The results show that at least 70% of the rain received at the three sites in 2001/2002 rainy season was acidic (Figure 3). Rain water with pH 5.6 or greater is considered alkaline while that with less than this value acidic (Guerzoni *et al.*, 1995). In 2002/2003 and 2003/2004 rainy seasons 60% of the rain received at Airport and Belvedere (figure 4 and 5) had normal to alkaline pH values. Jonnalagadda *et al.*, (1994), using composite rainwater samples to measure pH at Belvedere, found that all six samples had pH>5.6. The comparison of these results, however, presents difficulties due to differences in sampling procedures. Arex maintained a similar trend as in the preceding seasons (Figure 4 and 5). Lowest pH values were

recorded at Arex and continued to decrease from one season to another. These low pH values recorded at Arex could be due to a combination of high levels of sulphur dioxide, nitrogen oxides and less dust particles in the atmosphere than in other areas. It is estimated that Zimbabwe contributes 3% of sulphur emissions of the Southern African Development Community (SADC) of which Harare, Munyati, Hwange and Bulawayo constitute main points (Sivertsen *et. al*., 1995). Except for the coal power stations located to the west of the city, all major $S0_2$ producing industries in Harare (cement, fertiliser and chemicals manufacturing industries) are located in the direction of the prevailing wind.

A greater number of petrol vehicles in Harare are found in the low density residential areas in which Arex is located. It is thus likely that low pH values at this site could be due to a combination of industrial and vehicular emissions. The acidity of most rain samples of pH4 – 4.5 is equal to $[H^+]$ in highly concentrated fog waters (pH<2.5, HSO_4^- and $SO_2.H_2O$) become important species contributing to the strong acidity (Waldman, 1982).

Biomass burning contributes significantly to emission of trace gases and aerosol particles. Veldfires, which are more frequent in the Central-East and Southern Africa (Andreae, 1993; Earth Observatory, 2004), and the use of coal and firewood as a source of energy could also be other factors contributing to the formation of acid rain in Harare. In 2000 Zimbabwe accelerated the resettlement of people with subsequent opening up of new land for agricultural purposes and increased biomass burning. Fires and coal release volatile nitrogen oxides, ammonia and organics that can be transported over long distances (Scholes *et. al*., 1996). Lewis (1981) attributed the dramatic increase of H^+ and NO_3^- loading rates just following the onset of the rainy season to vegetation burning. In 2001 alone, coal accounted for about 61.8% and 94% fuel for power generation in Zimbabwe and South Africa respectively (World Bank, 2004). In Zimbabwe, veldfires are common between the months of August and November when the vegetation has shed most of its leaves and the grass dry.

Though Belvedere and Airport are located in areas of prevailing wind and high industrial activity, normal to alkaline pH values recorded at these sites were attributed to relatively high dust particles in the atmosphere (City of Harare, 2001; 2002). Although dust analysis could not be done due to limited resources, rainwater from Belvedere and Airport sites quite often contained reddish brown dust particles typical of the major soils found in and around Harare.

The significance of transboundary air pollution in affecting rainwater chemistry in Harare cannot be under-estimated. Trajectory modelling (Freiman and Piketh, 2003) has shown that a large percentage of aerosols and trace gases from the industrial region of South Africa are exported to neighbouring countries (with direct transport to Zimbabwe occurring about 15% of the time) and remote regions through direct transport.

Temporal Pb wet deposition

The concentration of Pb in rainwater depended on the rainfall amount and the length of the dry spell (figures 6 to14). Since all the three sites were affected by wind coming from the same direction, the influence of this factor on Pb concentration in rainwater seemingly appeared irrelevant. Very high Pb concentration in rainwater was recorded when the rainfall amount was less than 20mm per day. As the rainfall amount increased above 20mm so was the decrease in the concentration of Pb due to dilution effect. A relatively long period of dry spell followed by a rain event resulted in high levels of Pb concentration in rainwater. The contribution of dry deposition becomes a very important factor after a long dry spell. These trends are similar to those noted by Carbon (1999). The 2001/2002 rainy season was a drought one hence Arex and Belvedere experienced very high Pb concentration at each rain event due to the accumulation of pollutants in the atmosphere and the contribution of dry deposition (Figure 2 and 4). Though the mean concentration of Pb in rainwater decreased in 2002/2003 the wet flux in that year increased due to increased amount of rainfall received during that season (Table 1 and 2). At the end of February and the month of March, a cyclone (called Japhet) affected Harare from the north-western direction and could have brought rainwater with less Pb concentration. Increased vegetation cover during this period might have reduced the detachment of dust particles from the ground. Average wind speed of 20km hr^{-1} was recorded in Harare.

High peaks of Pb in rainwater in 2002/2003 at Arex in December and March (Figure 9) were probably due to localised washout of Pb from paint industries and motor vehicle emission that use leaded petrol. An estimated 95% of the vehicle that use petrol in Zimbabwe run on leaded petrol. In general quite a large proportion of vehicle fleet in Zimbabwe is more than 10 years old and this can exacerbate the lead problem. Ageing vehicles (>10years) are said to emit five times more hydrocarbon and carbon monoxide and four times more NOx than new ones (World Bank, 1995). Although it is difficult to compare Pb concentrations in rainwater from areas of different geographic locations due to varying sampling and analytical procedures, our results (Table 1 and 2) are of the magnitude ten times higher than those reported by Ngugen *et al.*, (1990) and Jaradat *et al.*, (1999) in industrial and urban areas. In Zimbabwe, Nyika *et al.,* (1996) reported mean Pb concentration in composite rainwater samples of 1.45ug l^{-1} in the 1991-1992 rainy season compared to our result of 2.96mg l^{-1} ten years later. The latter researchers attributed traces of heavy metals in rainwater to anthropogenic sources such as mine dumps. The surrounding industrial area and petrol storage tanks could be another source of lead in the atmosphere affecting Belvedere area.

Spatial Pb wet deposition

Except for Airport, which seems to be far away from the industrial influence, the first rains received at the Arex and Belvedere sites were “sooty” indicating the wash out of industrial, tyre and waste material burning and vehicular emissions, from the atmosphere. Veldfires, tyre and waste material burning, though illegal, are common practices in the city and its environs (City Health, 2001; 2002). The latter sites

experience the north-east wind direction (Figure 2 and Table 3) which possibly carries Pb emitted by the heavy industries located in that direction. In 2001/2002 and 2002/2003 rainy seasons, Arex and Belvedere sites had the largest Pb flux which can be attributed to industrial, vehicular emissions, and the contamination of the rainwater by dust particles. However, in 2003/2004, Arex had the largest Pb flux which was four times higher than Airport and 17 times higher than Belvedere. This difference can be explained by the reduction of industrial activity on the western part of the city and the changing wind direction.

Rainwater cationic composition

The cationic composition and electrical conductivity of rainwater received at different places is shown in Tables 3, 4 and 5. At all the studied sites the concentration of basic cations, and correspondingly conductivity, were highest at the beginning of the rainy season and when there was a relatively long period before the next rain event. This phenomenon, which was prevalent in the 2001/2002 drought year, could be attributed to the flushing of aerosols by rainwater.

Conclusion

Arex consistently received acid rain over the four-year study period while Airport and Belvedere experienced rainwater with normal to slightly alkaline pH in the last two years. The problem of acid rain is not only limited to cities in the developed countries but also developing ones like Harare. The seasonal Pb concentration in rainwater was more than ten times higher than those reported in similar areas indicating high levels of pollution. Besides industrial and vehicular emissions into the atmosphere, acid and Pb pollution in Harare could be due to long range transport of these substances by wind. The systematic phasing out of leaded petrol and monitoring of industrial emissions into the atmosphere could possibly reduce the problem of acidity and Pb in the atmosphere.

Acknowledgements

Data on vehicle numbers and rainfall were obtained from the Central Vehicle Registry and Meteorological Department respectively. The Harare City Council provided information on sources of air pollution. The National Oil Company of Zimbabwe provided valuable data on Pb levels in fuel. We appreciate the co-operation of these institutions

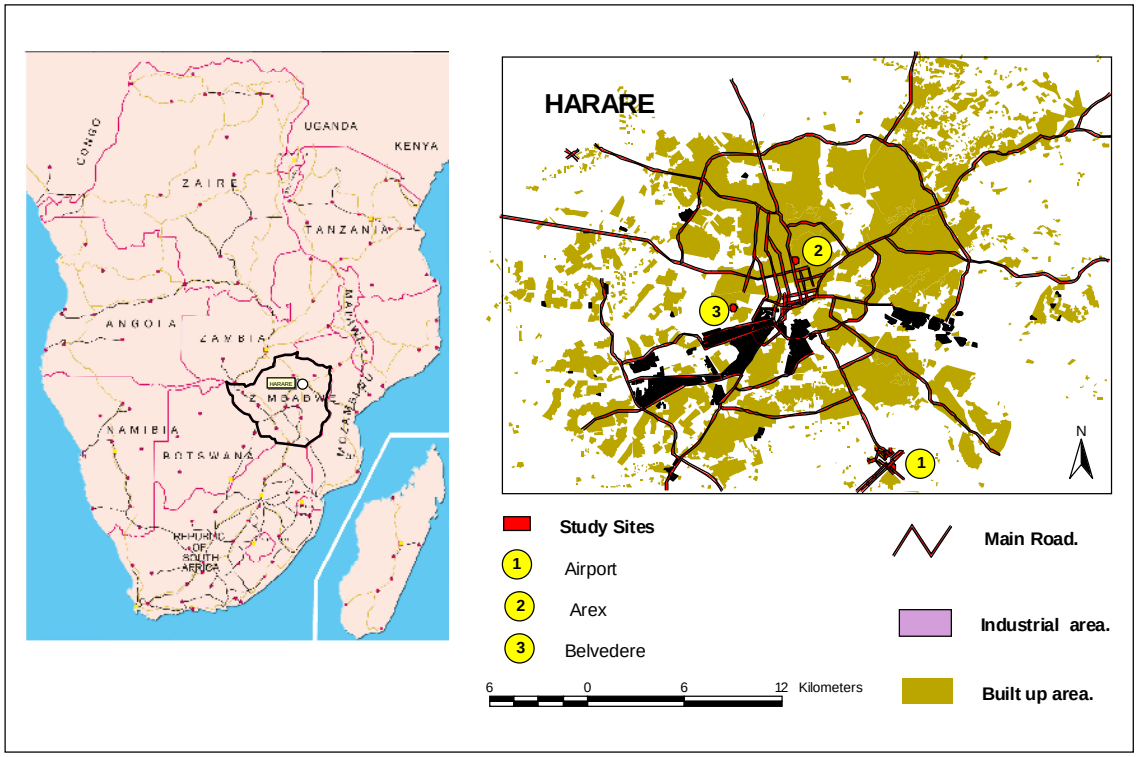

Figure 1. Location map of the study sites.

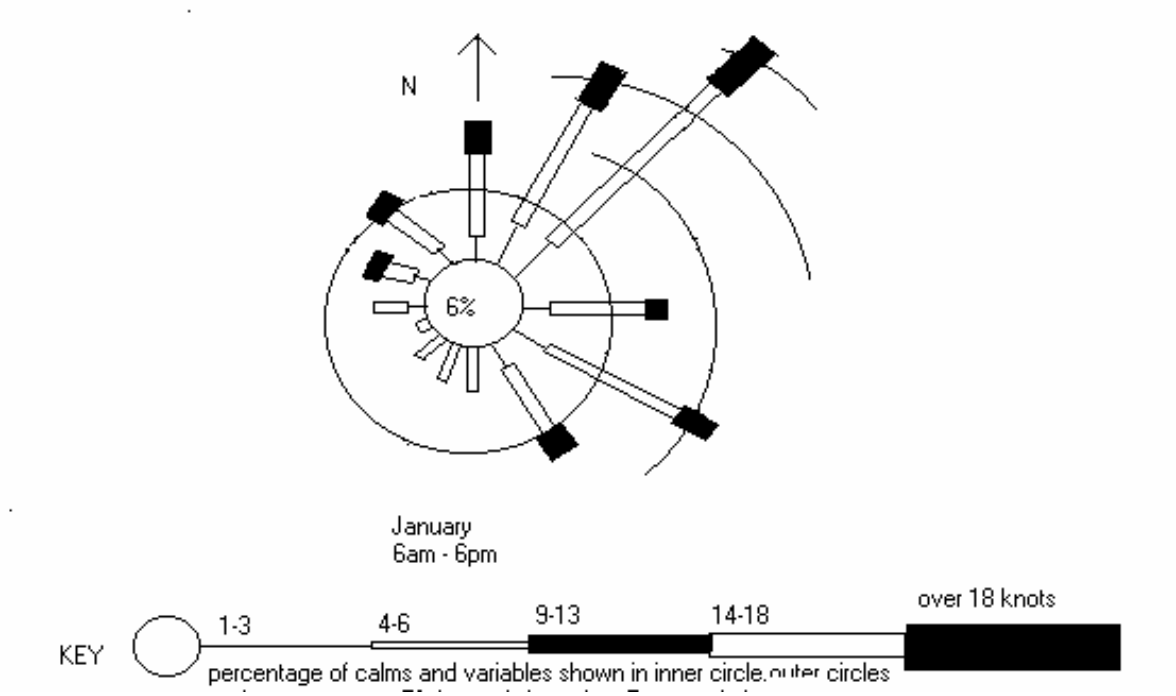

Figure 2. Typical windroses showing the prevailing wind direction in Harare

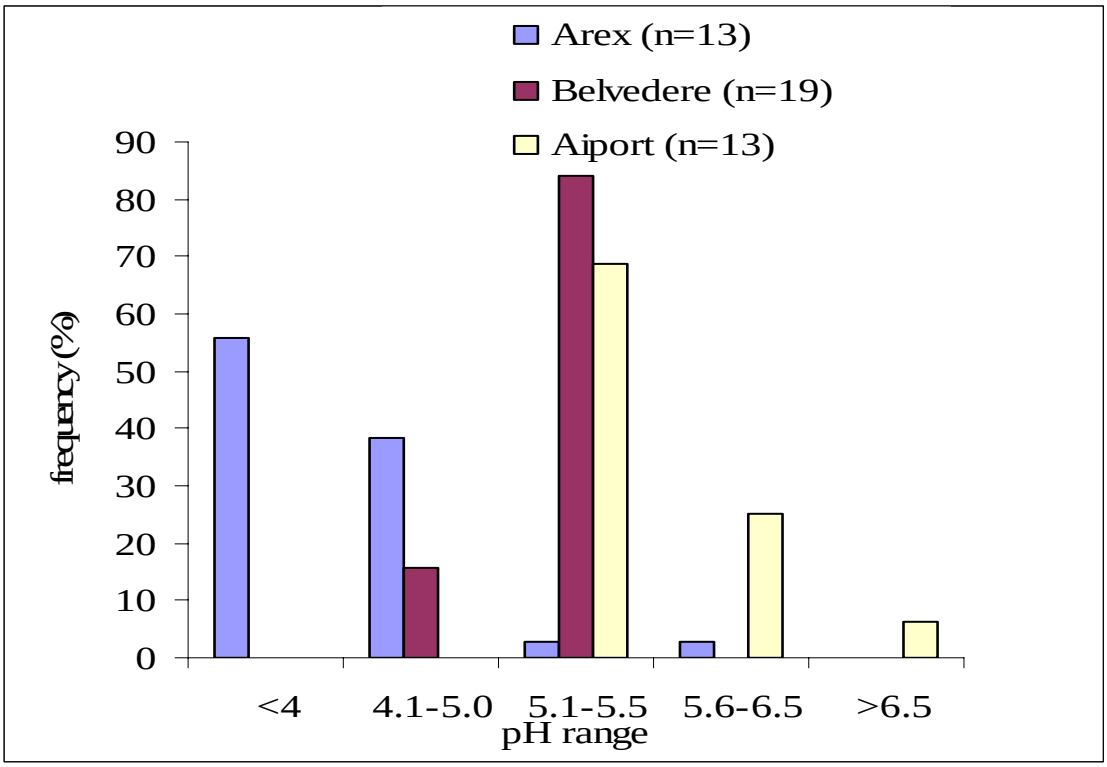

Figure 3. Spatial pH variation at three sites in 2001/2002 rainy season

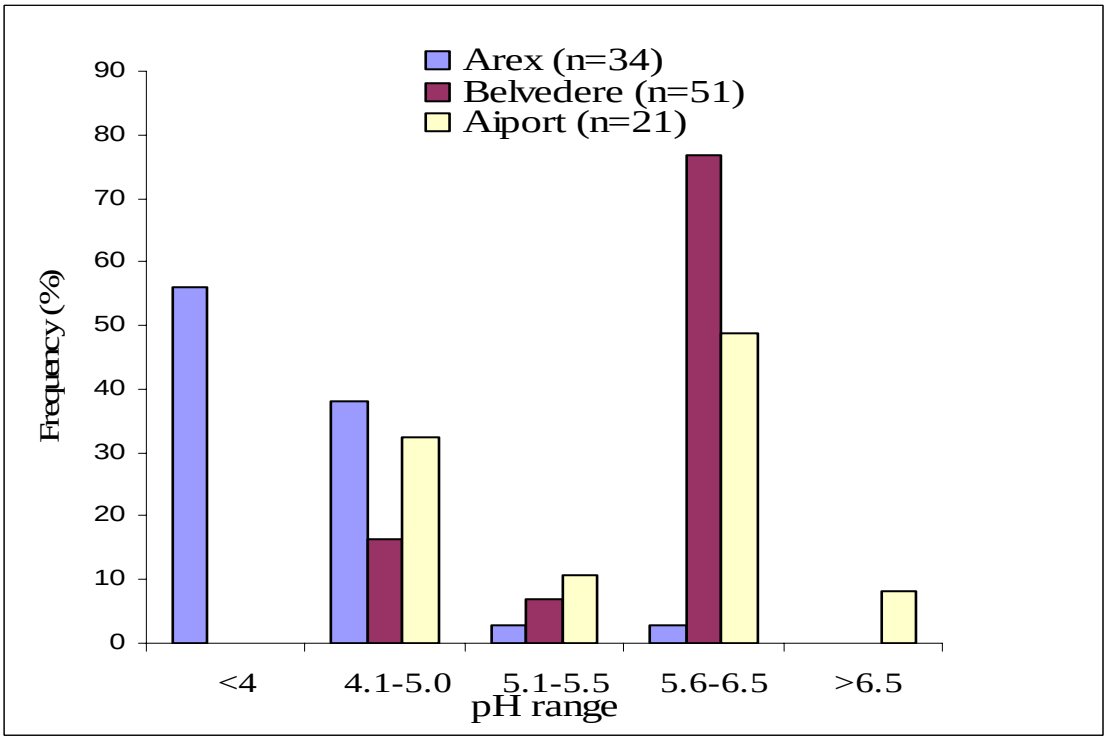

Figure 4. Spatial pH variation at three sites in 2002/2003 rainy season

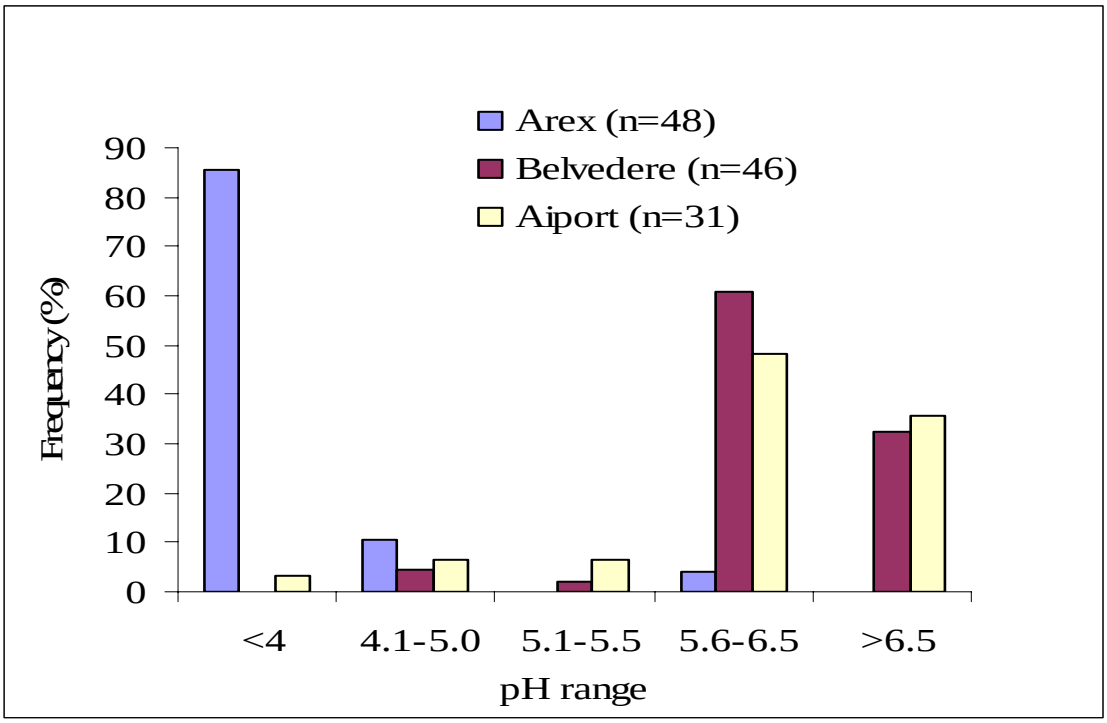

Figure 5. Spatial pH variation at three sites in 2003/2004 rainy season

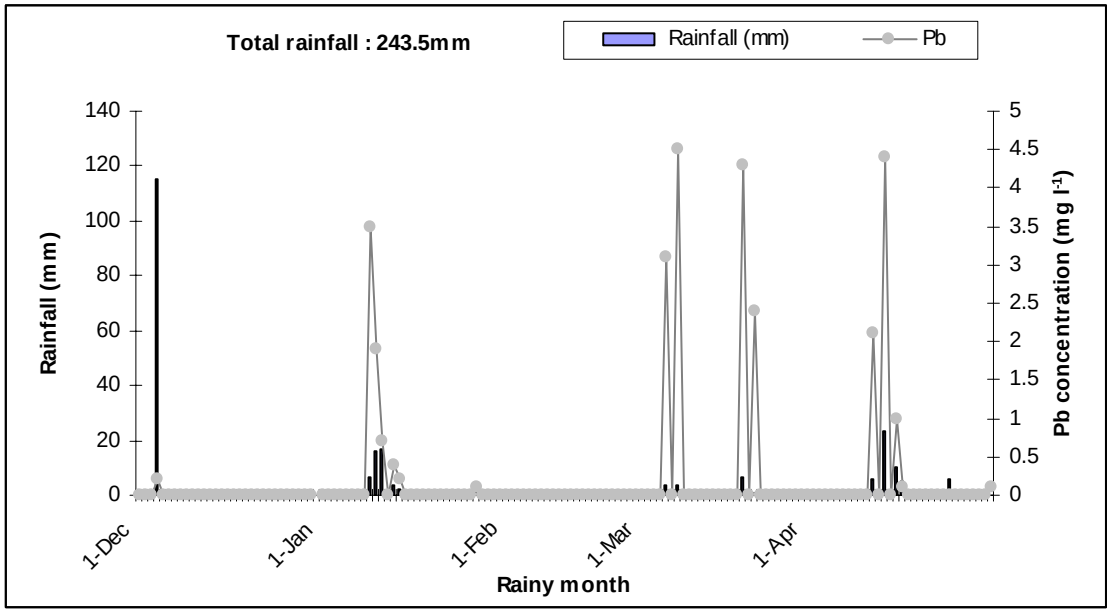

Figure 6. Pb wet deposition at Arex in 2001/2002 rainy season.

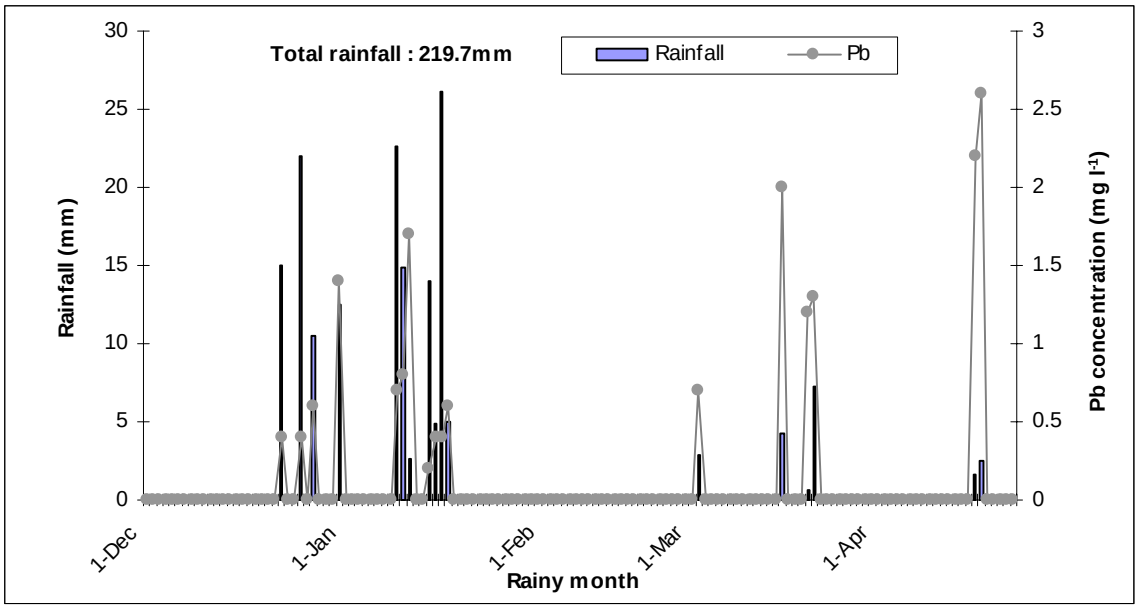

Figure 7. Pb wet deposition at Airport in 2001/2002rainy season in Harare

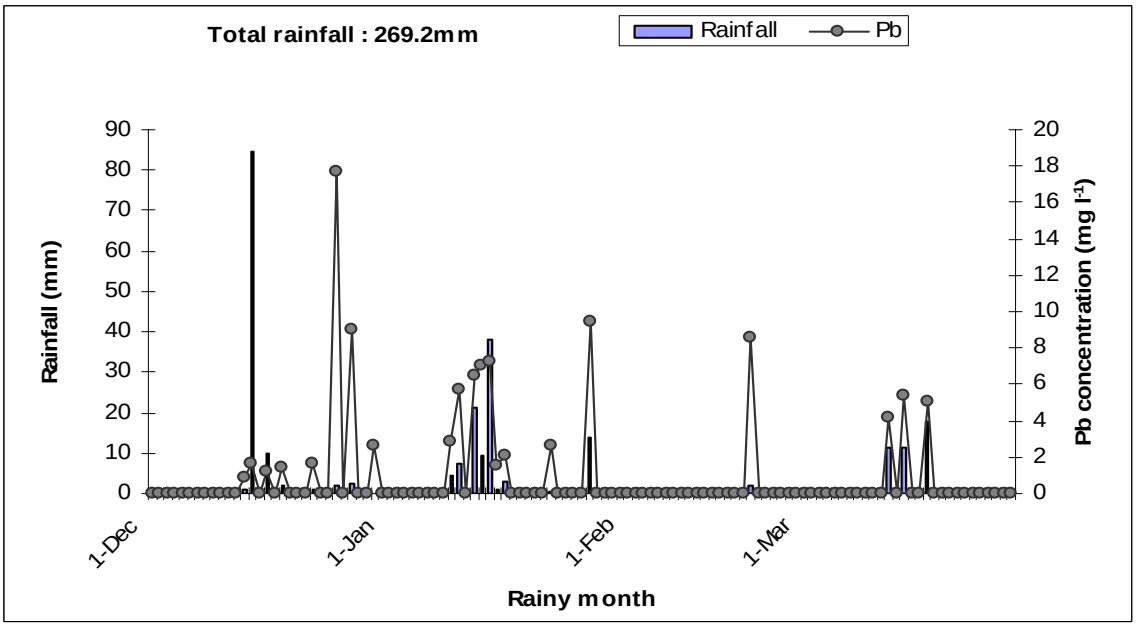

Figure 8. Pb wet deposition at Belvedere in 2001/2002 rainy season.

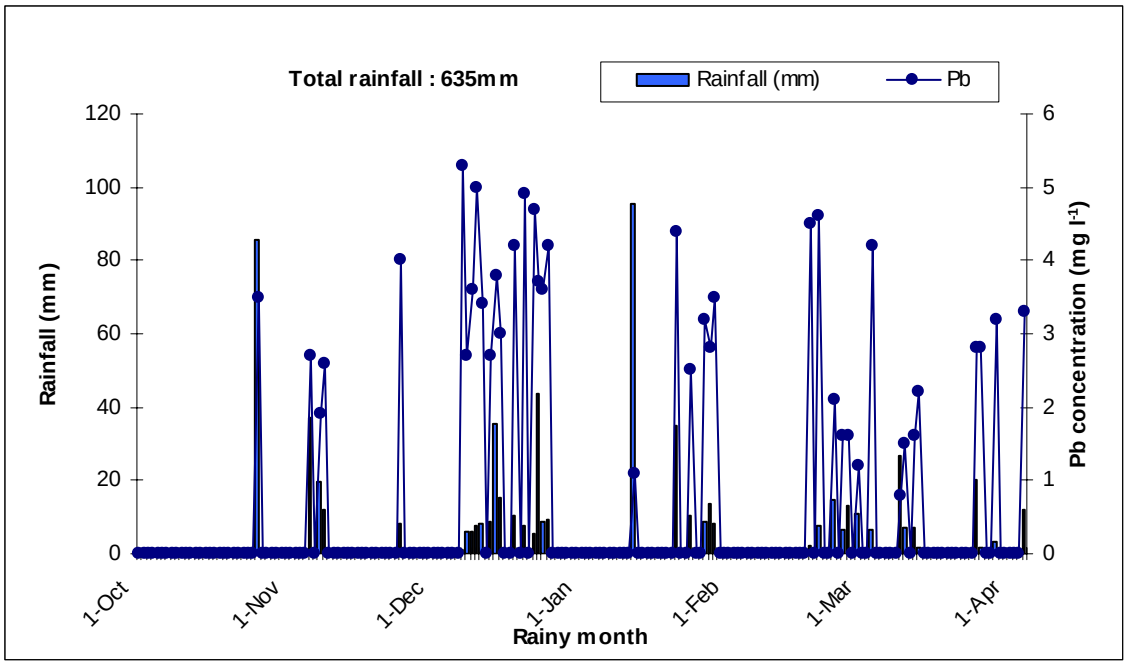

Figure 9. **Pb wet deposition at Arex in 2002/2003 rainy season.**

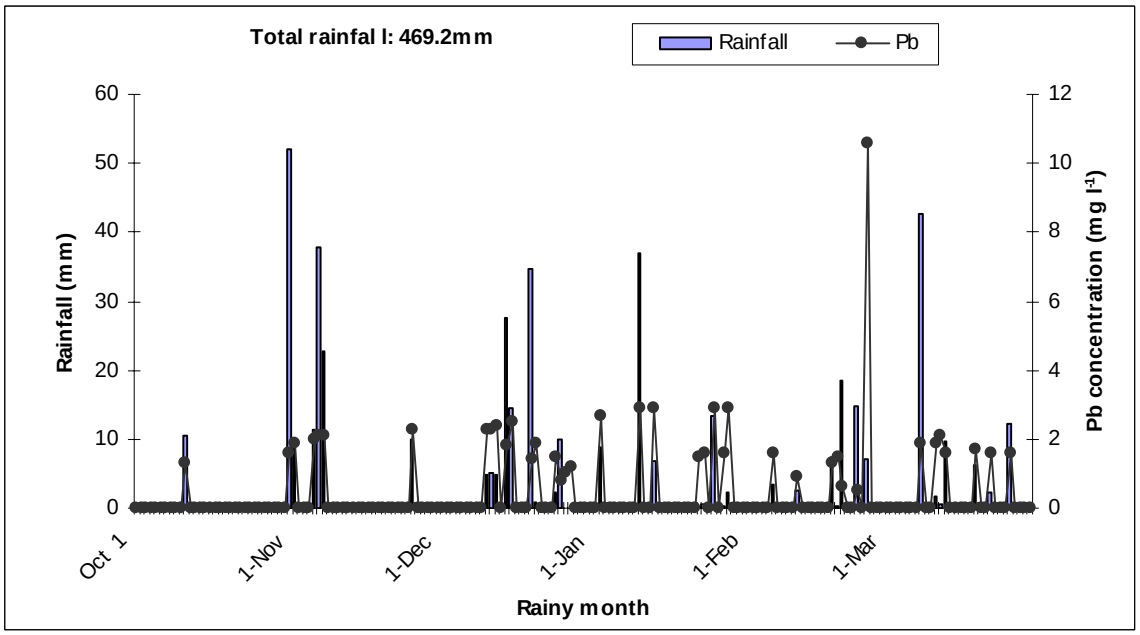

Figure 10. **Pb wet deposition at Airport site in 2002/2003 rainy season**

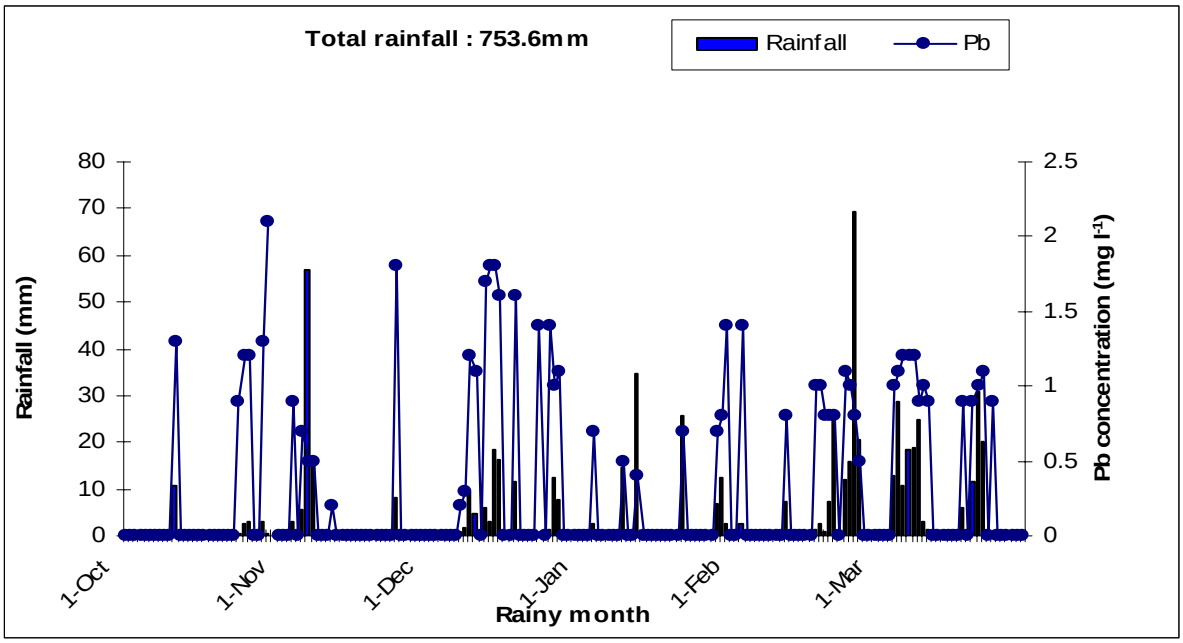

Figure 11. **Pb wet deposition at Belvedere site in 2002/2003 rainy season**

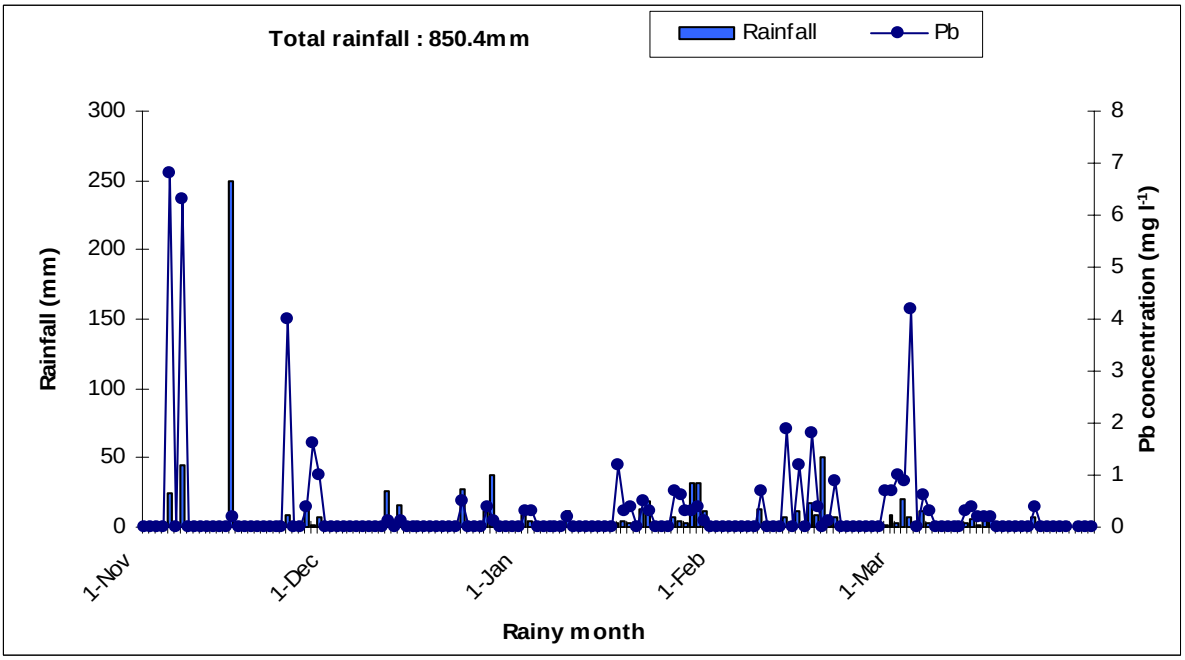

Figure 12. **Pb wet deposition at Arex site in 2003/2004 rainy season**

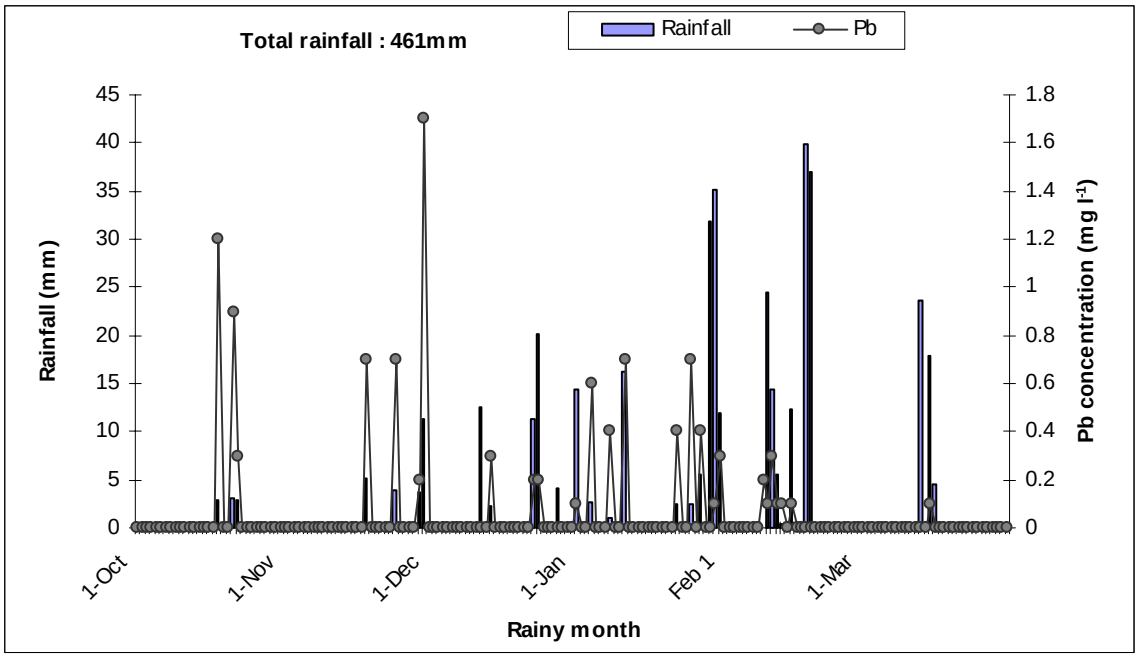

Figure 13. **Pb wet deposition at Airport site in 2003/2004 rainy season**

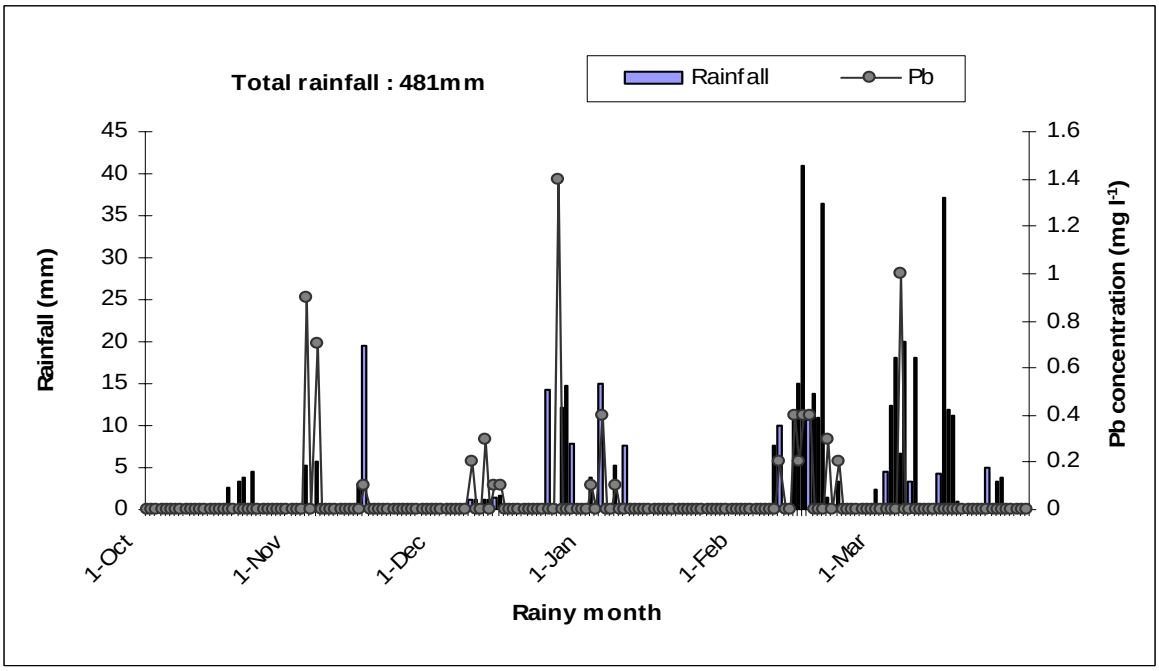

Figure 14. **Pb wet deposition at Belvedere site in 2003/2004 rainy season**

Table 1.Seasonal mean Pb concentration (± standard error) in rainwater at three sites

SITE	Pb Concentration (mg l^{-1})		
	2001/2002 season	2002/2003 season	2003/2004 season
AREX	2.06 ± 0.44	0.82 ± 0.15	0.78 ± 0.03
AIRPORT	0.83 ± 0.13	1.01 ± 0.05	0.34 ± 0.07
BELVEDERE	2.96 ± 0.54	0.96 ± 0.04	0.08 ± 0.02

Table 2. Seasonal wet Pb deposition flux (mg m^{-2}) at three sites

SITE	Pb wet deposition flux (mg m^{-2})		
	2001/2002 season	2002/2003 season	2003/2004 season
AREX	501.6	520.7	663
AIRPORT	182.4	473.9	156.7
BELVEDERE	796.8	723.5	38.5

Table 3. Cationic composition of rain water received at Airport Site

Parameter		**Month**						
		October	November	December	January	February	March	April
Ca (mg l^{-1})	**A**[1]	0	0	5.4±0.39	7.0± 0.34	0	9.5± 0.87	11.1± 0.1
	B[2]	5.3±2.4	4.4±0.7	7.2±1.0	4.0±1.7	0.6±0.1	1.2±0.07	0
	C[3]	13±4.0	6.3±3.3	5.6±2.2	3.8±0.7	3.0±0.1	4.7±0.7	0
Mg (mg l^{-1})	**A**	0	0	1.25± 0.19	0.97±0.1	0	1.1± 0.37	0.8± 0.4
	B	ND[4]	ND	0.7±0.27	2.0 ± 0.01	2.0±0.01	1.7±0.3	0
	C	3.3±1.3	3±1.0	2.0± 0.1	2.0 ± 0.1	1.1±0.4	0.7±0.7	0
K (mg l^{-1})	**A**	0	0	8.5± 6.9	11.1±5.2	0	144.1± 50.2	3.1± 0.1
	B	1.2± 0.7	0.9 ± 0.5	0.9±0.5	0.6±0.1	0.7±0.2	3.1± 0.5	0
	C	1.1± 0.3	0.8 ± 0.1	0.9±0.8	0.2±0.1	0.1±0.1	0.04±0.01	0
Na (mg l^{-1})	**A**	0	0	14.1±10.9	4.5±1.3	0	26.9±15.8	2.2± 0.8
	B	1.1±0.7	0.5±0.2	0.8±0.2	0.8±0.6	0.93±0.2	7.6±1.3	0
	C	3.1±1.1	1.7±1.4	0.6± 0.3	0.4±0.1	0.2±0.1	0.2±0.01	0
Conductivity	**A**	0	0	23.3± 3.1	20.7±2.7	0	335.9±194.6	19.3±2.2
(µScm^{-1})	**B**	28.4±8.2	28.9±5.3	31.8±5.9	20.7±1.7	38.5±3.1	66.9±4.9	0
	C	164.9±74.9	76.9±22.1	37.5±4.3	59.1±10.8	29.9±5.08	32.1±3.3	0

Table 4. Cationic composition of rain water received at AREX meteorological Site

Parameter		Month						
		October	November	December	January	February	March	April
Ca (mg l^{-1})	**A**	0	0	37.2± 0.21	9.8± 0.2	0	11.9± 0.3	9.7±0.1
	B	ND	ND	0.7± 0.3	2.0±0.01	2.0±0.01	1.8± 0.3	0
	C	0	9.3 ± 1.8	4.9± 0.8	4.0±0.4	6.4±0.7	5.3±0.3	0
Mg (mg l^{-1})	**A**	0	0	4.0± 0.4	ND	0	0.7± 0.2	0
	B	ND	ND	0.7± 0.27	2.0 ± 0.01	2.0 ± 0.01	1.7± 0.3	0
	C	3.3 ± 1.3	3 ± 1.0	2.0± 0.1	2.0 ± 0.1	1.1±0.4	0.7± 0.7	0
K (mg l^{-1})	**A**	0	0	3.2±0.1	ND	0	0.05±0.02	0.15±0.1
	B	0.3 ± 0.1	0.7± 0.3	1.0± 0.4	0.9 ± 0.2	0.8 ± 0.1	1.0±0.05	0
	C	0	1.3± 0.5	0.2± 0.01	0.2±0.1	0.1 ± 0.01	0.01±0.01	0
Na (mg l^{-1})	**A**	0	0	1.9± 0.2	ND	ND	ND	0.4±0.2
	B	0.5 ± 0.	1.1± 0.2	1.1± 0.5	1.3± 0.7	0.4± 0.1	0.3± 0.2	0
	C	0	1.9± 0.7	0.5± 0.3	0.3± 0.1	0.3±0.1	0.8±0.1	0
Conductivity	**A**	0	0	128.4±25.1	105±10.1	0	195.4± 36.5	11.3±32.2
(µScm^{-1})	**B**	85.5±0.5	64.7±23.1	84.1.8±15.9	70.3±17.8	52.6±10.1	51.1±11.2	0
	C	0	326.2±106.2	75.8±19.4	118.2±17.9	101.9±12.6	125.8±10.8	0

Table 5. Cationic composition of rain water received at Belvedere meteorological Site

Parameter		Month						
		October	November	December	January	February	March	April
Ca (mg l^{-1})	**A**	0	0	7.6 ± 1.1	9.6± 0.1	0	7.5± 1.7	6.8± 2.3
	B	4.0±0.6	6.8±1.5	5.6 ± 0.9	7.3±0.4	6.8±0.9	16.2± 1.4	0
	C	9.3±5.2	6.4 ± 2.0	7.3 ± 1.6	4.0 ± 0.4	5.2±1.0	8.0 ±1.0	0
Mg (mg l^{-1})	**A**	0	0	2.5± 0.1	1.8±0.3	0	2.2 ± 0.2	2.4±0.1
	B	2.3±0.7	2.4±0.4	1.2 ± 0.3	0.8 ± 0.4	1.7± 0.2	1.7 ± 0.2	0
	C	2.7±1.8	2.6±0.4	2.7± 0.6	1.8 ± 0.2	1.0±0.3	0.6 ± 0.2	0
K (mg l^{-1})	**A**	0	0	3.6±1.7	5.4±3.1	0	13.1± 7.9	5.9±4.7
	B	2.4 ± 0.8	0.9 ± 0.3	1.7 ± 0.9	2.2 ± 1.4	1.1± 0.8	0.7± 0.3	0
	C	1.1±0.7	0.8 ± 0.4	0.7 ± 0.3	0.1±0.01	0.1±0.01	0.02±0.01	ND
Na (mg l^{-1})	**A**	0	0	4.2± 1.9	5.0±2.0	0	19.8±11.5	13.2±9.1
	B	2.3 ± 0.3	1.5 ± 0.3	1.0± 0.3	0.6±0.3	2.5 ± 2.0	9.6±4.3	0
	C	1.5±0.7	1.8 ± 0.8	0.5± 0.3	1.7±0.7	0.2±0.01	6.2±0.1	4.7±3.8
Conductivity	**A**	0	0	33.5±8.2	33.6±6.6	0	101.3± 21.0	74.9± 40.2
(µScm^{-1})	**B**	174.3±43.5	82.0±26.7	84.1± 15.9	50.7±7.1	43.6 ±10.4	37.1± 9.1	37.3±7.3
	C	187.4±86.6	112.0±50.1	139.4±53.8	53.8 ±6.6	40.3±6.8	85.9±18.9	0

A[1]-2001/2002 rainy season, **B**[2]-2002/2003 rainy season, **C**[3]-2003/2004 rainy season
ND[4]- Not detectable, **0**-No rainfall recorded

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