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Lichens as Monitors of Aerial Heavy Metal Pollutants in and around Kampala

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The use of ion exchange resins and biological materials has aroused much interest in the search for inexpensive devices for monitoring pollution. Recent investigators (Everett et al. 1967, Martinez et al. 1971) have shown that plants themselves may be used as indicators of aerial fallout of heavy metals. Other workers (Goodman and Roberts 1971) have pursued the concept of using biological materials still further, by using mosses as indicators of aerial metal depositions. Lichens possess remarkable ion-exchange properties similar to many ion-exchange resins (Knight et al. 1961) and are there fore suitable for the collection and retention of airborne metals (Roberts 1972). Consequently, the levels of metals in lichens are of particular importance in environmental and geochemical studies. Lichens have been shown to be good indicators of pollution level; a close correlation is usually found between the distribution pattern of lichen species and the trace metal content of the surrounding air (Bioleau et al. 1982).

This study was undertaken to determine the degree of contamination of the Kampala, Uganda environment by heavy metals from industries and motor traffic by using lichens as an indicator device. One type of lichen species (Calymneferes usambaricum) was used as the test plant.

MATERIALS AND METHODS

A large and representative number (150) of lichen samples was collected from selected sampling sites 1 to 10. Background samples were collected from sampling sites Kyebando, Golf course, Kasubi and Nsambya which are outside urban influence and supposedly unpolluted

All the samples were carefully collected and taken to the laboratory with minimum contamination. They were then dried in an oven maintained at 85°C for 24 h cooled in a desiccator and ground to pass an 80-mesh sieve. Duplicate sample portions (1.50 g each) were digested with a concentrated nitric acid (10 mL), perchloric acid (1.0 mL) and hydrofluoric acid (5 mL) mixture. The digestion, performed at 140°C, was continued until the digestion mixture decreased to 1-2 mL in volume. Then, 40% hydrogen peroxide (10 mL) was added to complete the oxidation of the organic matter. The resulting mixture was allowed to evaporate to dryness. Then, concentrated hydrocholoric acid (2.0 mL) was added, and the mixture was heated again and then to dryness. The final residue was dissolved in 2M hydrocholoric acid (2 mL) and diluted to 25mL with distilled water. Lead, cadmium, and nickel were determined by direct aspiration of the main sample solution into an atomic absorption spectrometer. In the analysis of iron, calcium and magnesium, a dilution factor of 20 was necessary. All the duplicate determinations for each sample were accomplished with flame atomisation.

RESULTS AND DISCUSS

Analysis of ten lichen samples was completed to demonstrate the applicability of the digestion procedure. After it was ascertained that complete dissolution of lichen samples could be achieved, a fortification solution containing six elements, known to be present in lichens, was added to the sample. The digestion procedure performed with subsequent analysis by atomic absorption spectrometry gave the results given in Table 1. The accuracy ranges from an average of 96% for nickel to an average of 103% for magnesium. This

Table 1. Accuracy and precision based on five lichen samples

Element	Fortification (μg/mL)	Accuracy (%)	95% confidence level
Calcium	25	99	24.5± 0.2
	50	100	49.3 ± 0.2
	75	97	76.1 ± 0.3
Magnesium	25	103	26.2 ± 0.1
	50	102	51.4 ± 0.1
	75	103	74.4 ± 0.2
Cadmium	25	98	23.3 ± 0.2
	50	99	49.7 ± 0.2
	75	100	74.5 ± 0.2
Lead	25	97	26.5 ± 0.3
	50	99	51.2 ± 0.2
	75	100	70.1 ± 0.3
Iron (II)	25	103	24.3 ± 0.4
	50	100	49.2 ± 0.3
	75	102	74.4 ± 0.4
Nickel	25	96	24.3 ± 02
	50	98	47.6 ± 0.2
	75	100	75.4 ± 0.3

is an indication that the digestion procedure is sufficiently accurate for the analysis of environmental samples. Chemical analysis of lichens, collected from various sampling sites, shows that the concentrations of calcium, magnesium, cadmium lead, iron and nickel in samples from urban areas are higher than those collected from rural areas. This is indicated in Table 2 which represents the average and standard deviations for both samples from rural and urban locations. In the design of the sampling network, Kyebando, Golf course, Kasubi, and Nsambya were specially chosen to provide rural sampling sites; Bwaise, City centre, Kisenyi, Kamwokya, Industrial area and Katwe as urban sampling sites. Greatest variations between different sampling sites within the urban area were observed in the case of Cd, Pb, Fe and Ni concentrations. Heavy metals were found at highest concentrations in lichens collected from urban sampling sites. The lowest concentrations of those elements were recorded in the lichens from rural sampling sites. The rural area, where cadmium is accumulated at levels ranging from 0.5 to 2.8 μg/g and Pb from 80 to 150μ/g, appears to be relatively clean. In contrast to cadmium and lead, concentrations of calcium and magnesium do not show such marked variations between sampling sites of rural and urban areas.

Table 2. Concentration of elements in lichens collected from Rural and Urban areas

Element	Urban μg/g		Rural μg/g	
	$\bar{X}^a$	RSD[b]	$\bar{X}^a$	RSD[b]
Calcium	12500	5.5	11200	3.8
Magnesium	2970	4.6	2750	3.6
Cadmium	4.94	18.9	2.31	4.7
Lead	246	15.0	148	4.5
Iron	13400	14.0	8360	3.3
Nickel	79.6	8.5	71.30	4.8

[a]Mean value of metal concentration

[b]relative standard deviation based on analyses of a number of samples from 4 urban locations and 4 rural locations.

In addition to examining means and ranges for each element, the interelemental relationship has also been determined. These relations have been evaluated to date by least-squares regression analysis. These statistical evaluations have been applied to all the data obtained in this study. The results of this computation are presented in Tables 3 and 4.

Table 3. Linear correlation coefficients for urban samples.

	Ca	Mg	Cd	Pb	Fe	
Ca	1.00					
Mg	0.85	1.00				
Cd	0.52	0.47	1.00			
Pb	0.02	0.32	0.87	1.00		
Fe	0.48	0.49	0.67	0.64	1.00	
Ni	0.18	0.23	0.70	0.57	0.75	1.00

Table 3 represents the linear correlation coefficients for the data collected at the representative urban locations for all possible elemental pairs. In this statistical investigation, n = 20 and the number of freedom is n-2=18. For this number of data used, correlation coefficients of about 0.40 and greater would indicate a statistically significant ($p>0.05$) relationship. Table 3 shows that elemental pairs Pb/Ca, Pb/Mg, Ni/Ca, and Ni/Mg are not correlated with each other, whereas the rest of elemental pairs show correlations with the same elements and with each other. Table 4 shows the linear correlation coefficient matrix for the sampling site within the rural area. The elemental pair Mg/Ca, Cd/Ca, Pb/Ca, and Fe/Ca are correlated with each other; this signifies that each paired elements originate from the same source.

Table 4. Linear correlation coefficients for rural samples

	Ca	Mg	Cd	Pb	Fe	Ni
Ca	1.00					
Mg	0.88	1.00				
Cd	0.44	0.32	1.00			
Pb	0.03	-0.27	0.45	1.00		
Fe	0.43	0.24	-0.01	0.34	1.00	
Ni	0.07	-0.27	-0.36	-0.20	0.27	1.00

To evaluate the general degree of heavy metal contamination of urban and rural areas, a synthetic pollution index (GRODZINKA 1978) was used. This was based on the following calculations:

$$\text{Pollution index} = \frac{\text{(Standardised values)}}{\text{number of elements}}$$

$$\text{Standardised value} = \frac{X - \bar{X}}{\bar{X}}$$

where $\bar{X}$ = mean concentration value for element X in mosses from all the sampling sites

X = concentration value for element X in mosses from each sampling sites.

On the basis of standardised values of four heavy metals (Cd, Pb, Fe, Ni) in lichens, and the pollution index values, the sampling sites may be classified as clean or as heavily contaminated. Those which are relatively clean include Kyebando, Golf course, Kasubi, and Nsambya where the pollution index value range between -0.57 to -0.19. Those contaminated by heavy metals include Bwaise, City Centre, Kisenyi, Kamwokya, Industrial area, and Katwe where the pollution index value are 0.29, 0.92, 0.77, 0.34, 0.97, and 0.69, respectively.

The contamination of Kampala municipality by heavy metals as determined by means of lichens corresponds with the network of the roads and the distribution of industrial emissions. Among the most heavily polluted are the City Centre, Kisenyi, Industrial area, and Katwe. Industrial area is heavily influenced by heavy industries and motor traffic. Kisenyi and Katwe have become affected by emmissions from metal works and heavy trafficked roads. City Centre is within reach of the emmissions from the numerous industries in industrial centre. Kyebando and Nsambya are the cleanest of all the sites sampled. These two sampling sites are situated far away from urban influence and heavily trafficked roads.

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