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Heavy Metal Contamination in Plants, Sediments, and Air Precipitation of Katonga, Simiyu, and Nyando Wetlands of Lake Victoria Basin, East Africa

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Recently, extensive work has been carried out to investigate contamination of the environment by heavy metals. In particular, it has been demonstrated that elevated levels of heavy metals are to be found in vegetation and soils in the vicinity of certain industries and near busy roads or within urban areas. Trace metals are present everywhere in the environment, occurring in varying concentrations in air, soil and all biological matter (Heinrichs & Mayer 1977). Before the technological times, the cycling of each metal was basically at a steady state and a tight control was maintained on its distribution in any given ecosystem. But today, the anthropogenic inputs have overwhelmed the natural biogeochemical cycles of trace metals in many ecosystems (Andrea et al, 1984). The consequence is that the increased circulation of toxic metals in plants, soil and air, results in the inevitable build-up of such toxins in the human food chain and living systems, and their accumulation are the concern of mot aircronmental protection agencies. Several authors have shown a relationship between atmospheric metal deposition and elevated metal concentrations in plants and top soils especially in cities and in the vicinity of metal-emitting factories (Andersen et al., 1978; Pilegaard, 1978). However, in relation to the bulk of agricultural crop production, the metal deposition in the rural background is of greater interest. The deposition on plants in East Africa background areas has mainly been recorded in moss and linchens (Nyangababo & Salmen, 1987; Nyangababo, 1987) as these plants which lack roots are mainly supplied with elements from the atmosphere. Agricultural plants grown in background areas will, however, also receive metals from the atmosphere, as is clearly shown for the fission products ^{90}Sr and ^{137}Cs., distributed worldwide from nuclear tests and deposited on crops (Aarkrog et al., 1980). A similar behaviour is reported for lead aerosols from car emissions transported long distances (Rabinowitz, 1972), as more than 90% of the lead in green plant originates from the atmosphere (Tjell et al., 1979). Metals are emitted to the atmosphere from several man made sources. Non-ferrous and ferrous metal production, fuel combustion and waste incineration are believed to be the main sources, while natural sources are comparatively minor (Nriagu, 1979). Besides metals emitted to the atmosphere may be transported up to several hundred kilometers, depending on emission height, meteorological conditions and the particle size distribution of the metal bearing particles (Nyangababo & Ichikuni, 1983). The mechanism of uptake of trace metals by plants is based on root uptake and foliar adsorption, including deposition of particulate matter on plant leaves. The initial step in evaluating the potential significance to plant health of metals introduced into the air and sediment of a wetland is to establish the plant burden and the location of various metals in the plants. The results of several studies (Parket et al 1978,) and the reports of research (Whittaker et al 1979,) suggest that the distribution of heavy metals in

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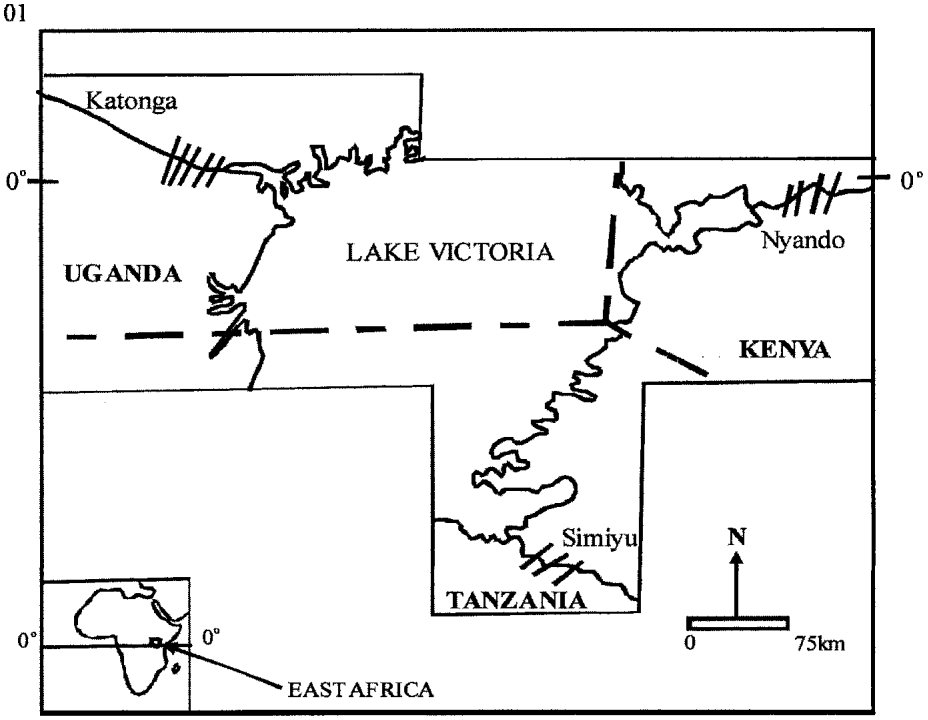

Figure 1. Locality of Katonga, Simiyu and Nyando wetlands on Lake Victoria Basin

wetland ecosystems varies appreciably but in most studies the tendency is toward an accumulation.

Wetland ecosystem contamination is fast becoming an issue of regional as well as global concern. The threat posed to human life and environment by contamination makes it mandatory to devise control measures to combat it. This would be facilitated by establishing reliable information about the source-receptor relationship of the pollutants. In this regard, identification and apportionment of sources by means of distribution and cycling studies have gained wide acceptance. The aim of this study was to quantify the amount of trace metals in plants and sediments, in the wetlands, originating from deposition of atmospheric metals and the amount taken up by the roots. This information is important in assessing the direct transmission of atmospherically emitted heavy metals to human food by plant material contamination. In order to produce realistic and representative values, the study was carried out in background areas of wetlands in East Africa far from obvious polluting sources.

MATERIALS AND METHODS

The sampling area is shown in Figure 1. The wetland areas have no industrial activity in the vicinity of the sampling locations. Sediment and plant materials were sampled from different localities within respective wetlands. At any one sampling site, within the wetland, at least three whole *cyperus papyrus* plants (roots, rhizomes, culm, leaves with flowers were sampled. The plant materials were dried at 105°C for 24 hrs, and ground to pass 80-mesh sieve. Duplicate 1.0g sample portions were ashed using a

mixture of 5.0 ml fuming nitric acid (90%) and 3.0 ml perchloric acid (70%) in uniseal digestion bomb. The digestion bomb with its contents was placed in an oven at 140°C for 3 hours and then cooled to ambient temperature. The resulting digest was diluted

Table 1. Heavy metal content in plants, sediment and in air precipitation samples from Katonga, Simiyu and Nyando wetlands.

Trace metal	Wetland					
	Katonga		Simiyu		Nyando	
	X±σ	E_F	X±σ	E_F	X±σ	E_F
Vegetation μgg-1						
Pb	7.83 ± 1.90	4	3.90± 0.35	1	0.34±0.054	1
Cd	1.08 ± 0.11	37	0.31±0.02	7	0.04±0.018	2
Cy	56.25 ± 14	7	9.81±2.60	8	11.3±3.05	2
Mn	140.31 ± 53	1	199.18±82	1	98.5±44.30	1
Zn	85.32 ± 11	8	22.04±7.90	2	7.14±2.57	1
Total	291		235		117	
Sediments μgg-1						
Pb	1.70±0.30	3	1.48±0.40	1	1.60±0.0.40	13
Cd	3.0±0.96	380	3.17±1.40	10	0.10±0.02	53
Cu	29.00±3.50	13	7.05±2.00	1	1.13±0.50	2
Mn	37.50±8.80	1	91.13±5.00	1	9.85±3.0	1
Zn	99.38±28	36	107.7±29.00	1.6	67.80±23	102
Total	171		211		80	
Air precipitation μgm^{-2} day -1						
Pb	0.083±0.05	30	0.05±0.01	4	0.069±0.06	92
Cd	0.009±0.01	219	9.054±0.02	273	0.0024±0.01	208
Cu	0.069±0.03	6	0.050±0.014	1	0.019±0.01	6
Mn	0.197±0.16	1	0.94±0.42	1	0.055±0.04	1
Zn	0.598±0.39	41	0.48±0.17	7	0.17±0.11	42
Total	0.956		1.58		0.32	

with dionized water and made up to 25.00 ml in a standard flask. This solution was then analysed for Pb, Cd, Cu, Mn and Zn by direct aspiration of the sample solution into atomic absorption spectrophotometer, instrumental laboratory Perkin Elmer model 3280, with detection limits and recoveries checked for all elements and found to fall, within 0.01 μg ml-1 and 95 – 102 respectively.

A few determinations were also carried out using the standard addition method, but these gave no significant difference in results from the normal calibration method, so the bulk of the solutions were analysed using the later method. For a particular study area the arithmetic mean of all results for that area was taken.

Sediment sampling in the wetlands was carried out at sites 50 to 80 m intervals within the wetland. At every site four sub samples of sediment (each being 30 to 50 cm) were taken in a random fashion to cover a site area of 2 to 3 meters square. The sediment samples were oven dried at 105°C for 24h, stones and grass roots were removed, and the sediment then ground up to pass 30-mesh sieve. The sieved material was then well mixed, and duplicate 0.50 g samples extracted with 10 ml of aqua regia. The resulting extracts were diluted with deionised water, filtered through Whatman No. 42 paper, washed through with dionized water, then made up to 25.00 ml in standard flasks. Analyses of the sediment solution were carried out for Pb, Cd, Cu, Mn and Zn using

the AAS 3280. The arithmetic mean of the analyses was taken as the value for a particular wetland. During the study periods, atmospheric deposition was sampled in a funnel (Hovamand et al 1983) in order to estimate the atmospheric input of trace metals to the experimental wetlands. The sampling device for bulk precipitation as a modified NILU – sampler (Norwegian Institute for Air Research) consisting of a polyethylene funnel with a 20.8 cm opening, connected to a 10-litre polyethylene bottle. The funnel opening was placed 1.5 m above the ground (Hovmand, 1977). A portion of bulk precipitation (500 ml) sampled in a one-month period was evaporated with 10 ml nitric acid to near dryness and dissolved in 25 ml of 1M HNO_3 in a standard flask. The analysis of air precipitation solution was carried out on Pb, Cd, Cu, Mn and Zn using atomic absorption spectrophotometry as outlined by Haig Agemian and Chau, 1975.

Geometric means and 95% confidence intervals are given because of positive Skewness in the heavy metal data. However, the same data are given as arithmetic means and standard errors for purposes of comparison with other published studies. Statistical separations of the means were by student's t, when variances were unequal, by l'(Snedecor & Cochran, 1967). Significance levels are as follows: One asterisk, P <0.2; two asterisks, 0.1 and three asterisk, $P < 0.05$.

RESULTS AND DISCUSSION

All the metals studied were detected in the samples from lake Victoria basin. Table 1 contains a list of the range of metal contents for all samples. Considerable differences were noted with respect to metal content in samples from Katonga, Simiyu and Nyando wetlands. Samples with metals present in elevated amounts relative to each of the wetlands studied, included the vegetation followed by the sediments. The total metal concentration in vegetation samples collected from Katonga wetland exceeds the total metal concentration in similar samples collected from Simiyu wetland which in turn has more than in samples from Nyando wetland (Table 1). In the case of sediment samples, the highest metal concentration is in samples collected from Simiyu wetland ecosystem followed by the Katonga wetland. The lowest metal concentration is found in sediment samples collected from Nyando wetland. With regard to air precipitation, Simiyu wetland receives the highest metal concentration than Katonga and Nyando wetlands. The study areas can be ranked according to total heavy metal content: the total in vegetation samples from Katonga wetland is 1.2 times higher than in vegetation samples collected from Simiyu and 2.5 times in samples collected from Nyando. The total in sediment samples from Simiyu is 1.2 times higher than Katonga; and 2.6 higher in samples collected from Nyando. The total in air precipitation at Simiyu is about 1.7 times in samples collected in air precipitation at Katonga and 4.9 times higher in air precipitation collected at Nyando.

Reference to the same Table I, shows that the trace metal concentrations in vegetation, sediment and air precipitation samples exhibit a trend of increasing levels in the order:

Vegetation,

Pb:	Katonga	>	Simiyu	>	Nyando
Cd:	Katonga	>	Simiyu	>	Nyando
Mn:	Katonga	>	Simiyu	>	Nyando
Zn:	Katonga	>	Simiyu	>	Nyando
			Sediment		
Pb:	Katonga	>	Nyando	>	Simiyu
Cd:	Simiyu	>	Katonga	>	Nyando
Cu:	Katonga	>	Simiyu	>	Nyando

Mn:	Simiyu	>	Katonga	>	Nyando
Zn:	Simiyu	>	Katonga	>	Nyando
		Air precipitation			
Pb:	Katonga	>	Nyando	>	Simiyu
Cd:	Katonga	>	Nyando	>	Simiyu
Cu:	Simiyu	>	Katonga	>	Nyando
Mn:	Simiyu	>	Katonga	>	Nyando
Zn:	Katonga	>	Simiyu	>	Nyando

Table 2. Comparison of mean levels for different types of wetlands (plants, sediment, air precipitation).

Metal	Mean metal levels			Level of significance		
	Katonga	Simiyu	Nyando	Katonga/ Simiyu	Simiyu/ Nyando	Nyando/ Katonga
Plants						
Pb	2.17	3.90	0.34	*	***	**
Cd	0.12	0.31	0.04	*	*	***
Cu	40.3	9.81	11.3	**	NS	**
Mn	123	199	98	**	***	NS
Zn	76	22	7.2	**	**	**
Sediment						
Pb	1.76	1.28	1.04	***	NS	NS
Cd	2.05	3.01	0.15	***	***	***
Cu	25.14	6.74	1.20	*	***	**
Mn	87	104	60	NS	NS	NS
Zn	99	107	68	NS	NS	NS
Air-precipitation						
Pb	0.067	0.042	0.063	*	NS	NS
Cd	0.006	0.048	0.002	***	***	*
Cu	0.052	0.050	0.017	***	NS	NS
Mn	0.146	0.92	0.053	**	**	*
Zn	0.543	0.467	0.169	NS	*	*

P < 0.05 *** NS: Not significant
< 0.1 **
< 0.2 *

The metal levels in vegetation samples are rather high and their interpretation is not simple. The plants receive fallout metals via wet and dry deposition directly on both leaves and bark. As a result of direct deposition on the soil from the atmosphere and indirect deposition via stem flow, heavy metals may enter the plants from the soil solution through the root system. Leaf and bark metals may be translocated to the plant. At each step towards plant accumulation of the heavy metals, some of them may be lost. Hence the plant metal content is a measure of the total metal input minus what is lost before the metals enter the plant tissues. However, it has been shown that plants grown on soil of high metal content take up only small amounts into their aerial parts, and that abnormal metal levels in the aerial parts are indicative of enhanced levels in the surrounding atmosphere (Burton and John, 1977). Thus it may be inferred that there is a steady increase in the atmospheric metal levels of the wetlands studied.

Reference to Table 2 shows that lead figures in vegetation exhibit a trend of increasing levels in the order Simiyu > Katonga > Nyando. Studies have shown that plants grown on soil of high Pb content take up only small amounts of Pb into their aerial

parts and that abnormal Pb levels in the aerial parts are indicative of enhanced levels in the surrounding atmosphere (Morten & Hammond, 1966; Schuck & Locke, 1970).
Thus it may be concluded that there is a steady increase in atmospheric Pb levels, the highest level being found in the Katonga wetland. Cadmium shows similar trend as in the case of Cd, the following order is observed; Simiyu > Katonga > Nyando. The same sequence is observed for sediment and air precipitation samples. With Cu, the following trend was observed: Katonga > Nyando ≈ Simiyu, in both plants, sediment and air precipitation, while in the case of Mn, the order shown in plant materials is Simiyu > Katonga > Nyando and in sediment samples Katonga ≈ Simiyu ≈ Nyando, while in air precipitation the trend observed is Simiyu > Nyando while in case of sediment and air precipitation, there would appear to be no significant trends in the levels of zinc, but the levels are significantly higher than those in plant materials.
Of the trace metals tested, manganese is in highest concentration in the earth's crust (Moson, 1966). In an attempt to understand the distribution of the elements of man-made origin, an attempt was made to assess the degree of contamination for the three study sites by individual elements in vegetation, sediment, and air precipitation samples. This was done by calculating the enrichment factor (E_F), using manganese as a reference element. The E_F for any element X in each of the samples can be calculated by the equation:

$$E_F = \frac{[X]sample/[Mn]sample}{[X]crustal/[Mn]Crustal}$$ (Andren & Lindberg, 1977)

The results of such calculation are shown in Table 3, and are such that elements which are naturally derived should have an E_F of nearly unity, while elements of man-made origin will have E_F values ranging to several orders of magnitude higher. The results indicate that for all the samples, vegetation, sediment and air precipitation, the values

Table 3. Average enrichment factors, F_E for various elements

Trace Metals	Enrichment Factors F_E		
	Katonga	Simiyu	Nyando
Vegetation			
Pb	4	1	1
Cd	37	7	2
Cu	7	8	2
Mn	1	1	1
Zn	8	2	1
Sediment			
Pb	3	1	13
Cd	380	10	53
Cu	13	1	2
Mn	1	1	1
Zn	36	2	102
Air precipitation			
Pb	30	4	92
Cd	219	273	208
Cu	6	1	6
Mn	1	1	1
Zn	41	7	42

for Katonga wetland range from 4 to 219, for Simiyu, the values range from 2 to 273 and for Nyando, the range is 2 to 208. On the basis of enrichment factors, it can be seen that the survey has shown that there are enhanced levels of the heavy metals Pb, Cd, Cu, and Zn in the vegetation, sediment and air precipitation of Katonga, Simiyu and Nyando wetlands.

The survey has shown that there is contamination by heavy metals Pb, Cd, Cu, and Zn in the Katonga, Simiyu and Nyando wetland ecosystems. The evidence supports the hypothesis that the enhanced levels are due mainly to aerial deposition. In the case of Pb, Cd, and Ni the primary source of pollution would appear to be the motor vehicles. These high metal levels in these wetland ecosystems do give cause for concern, especially to animals which graze by the wetland edges during dry season and humans who harvest some wetland plants as part of their diet. The results of this study demonstrate the critical need to extend our understanding of wetland protection from the preserve itself to the watershed as a whole. The effects of development should be seriously considered as well. Budd and Meals (1994) reported that runoffs contain substantial amounts of nutrients and heavy metals. As development pressure increases from both urban and agricultural sources, the integrity of natural wetlands will be increasingly compromised. Therefore a programme of survey and monitoring of the immediate catchment area of these prestige wetlands, should be established as check measures. Any potential environmental contamination can then be identified and abated and management strategies can be put in place for sustainability by controlling developments within Lake Victoria basin boundaries, including mitigating the impacts of urbanisation on wetland ecosystems, and providing ecological sustainability of wetlands.

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