OPTIMIZATION OF EDXRF FOR THE STUDY OF HEAVY METAL POLLUTION OF LAKE VICTORIA

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ABSTRACT

*This study reports on the optimization and calibration of the Energy Dispersive X-ray Fluorescence (EDXRF) spectrometer installed in the Department of Physics, University of Dar es Salaam. The spectrometer was subsequently utilized to determine concentrations of heavy metals in water hyacinth (*Eichhornia crassipes (Mart*) Solms.) found growing along the shore of Lake Victoria. The optimal conditions and detection limits were determined experimentally by variation of the excitation parameters. The study found that the use of a collimator with two apertures of diameter 4 mm each placed 8 mm apart and made of materials that do not interfere with elements to be determined from the samples, gave lowest detection limits. The optimal pairing of voltage and current was found to be 40 kV and 30 mA while measuring time was 2000 seconds.*

Roots of the water hyacinth were used in experiments to check the validity and sensitivity of the equipment. The water plants were collected from areas influenced by industrial and domestic sewage around Mwanza town, namely Mwanza South, Mwanza Central and Mwanza North. Mwanza North had quite a few industries and human settlements. The samples were each oven-dried, ground into a fine powder and pressed into a pellet. Water hyacinth from the industrial area and those from sewage discharge points were found to have higher concentrations of heavy metals (K, Ca, Sc, Ti, Mn, Fe, Co, Ni, Zn and Pb) than those from non polluted area. A more detailed study, involving more samples, is needed in order to be able to statistically quantify the differences.

INTRODUCTION

In the spectral analysis of trace elements the instrument is considered to be efficient when the detection limits, which is the minimum amount of concentration detectable by an instrument, are very low. Lowering the detection limits goes hand in hand with the reduction of background signal. For EDXRF this depends mainly on the screening of scattered radiation and the choice of optimal excitation conditions. Scattered radiation and excitation conditions are strongly correlated (Spatz & Lieser 1979). There are several factors which influence the detection limits. These factors include secondary target, sample and detector arrangements, system collimating, diameter of the collimator, high voltage and anode current of the X-ray tube and the measuring time. In this study all of these factors were optimized. The spectrometer was then used to analyze heavy metal content in water hyacinth from Lake Victoria.

METHODS

Optimization of the Energy Dispersive X-Ray

Fluorescence Spectrometer

An Energy Dispersive X-Ray Fluorescence (EDXRF) system (Fig. 1) measures x-ray fluorescence radiation emanating from inner shells of the atom. The system consists of an x-ray tube or small radioisotope excitation source, a detector with preamplifier, amplifier, a computer based multi channel analyzer (MCA) and a convenient computer software for fitting the spectra.

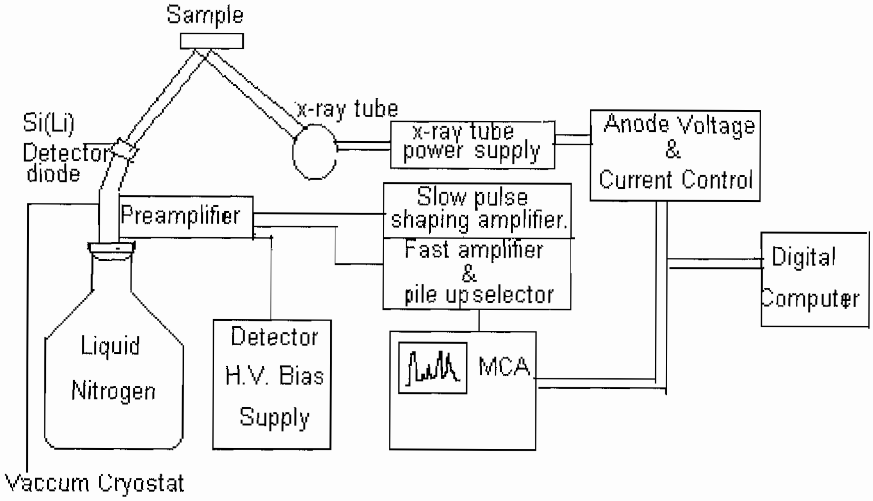

Fig 1: A block diagram of a typical EDXRF spectrometer.

In order for the system to give low detection limits, optimization of secondary target, sample and detector arrangement, collimators, voltage and anode current of the x-ray tube and the measuring time were done.

Secondary target

The secondary target produces the monochromatic x-rays and suppresses the *bremsstrahlung* and hence provides a cut-off in the background. Since the secondary target provides a narrow band of exciting energy just above the absorption edge of the highest energy line to be excited, it reduces the spread of characteristic x-ray radiation as well.

The main advantage of the secondary target technique (Van Grieken & Markowicz 1993) is the flexibility of the choice of the monochromatic excitation energies, allowing a fairly wide range of materials that can be used as secondary targets. However, the technique has a limitation of being very inefficient in utilizing the output intensity of the x-ray tube since only a small fraction of the fluorescent radiation from the secondary target is emitted. It also requires higher x-ray tube power than when a direct excitation is used. In this study, Molybdenum was used as a secondary target. The energy of the x-rays emitted from the Mo - secondary target is 17.4 keV, hence it can be used to analyze a wide range of elements from Si to Pb.

Collimation

In order to reduce the background and hence lower the detection limit, one has to reduce the beam spreading by removing the unwanted signals from the sides of the sample and detector by a combination of collimators. A collimator can be made from a set of four polished tantalum strips or from a hollow aluminium or lead block (Van Grieken & Markowicz 1993). The strips can be spaced with thin plastic or metal foil to produce an aperture.

We therefore constructed a double disc Lead collimator with Molybdenum apertures. The double disc collimator has the advantage that the unwanted signals which pass through the first aperture are absorbed by the second disc and only a narrow beam from the centre of the sample can reach the detector. The distance between the two discs can be calculated graphically if the aperture diameter of the collimator, active area of the detector, and the distance between the collimator and the detector are known.

In order to judge the optimum size of the collimator to be used in the study, four collimators of different diameters ranging from 4 to 10 mm were constructed. Each collimator was used in turn in the irradiation of the Standard Reference Material (SRM) 3087A metals on filter media. The detection limits of the elements in the standard as a function of collimator diameter were calculated and tabulated as in Table 1. The formula used for the calculation of detection limits was:

$$DL = \frac{3C}{N_p}\sqrt{\frac{N_b}{t}}$$

where DL = Detection limit.
C = Concentration of the element.
N_p = Net peak count rate.
N_b = Background count rate,
t = Measuring time.

Table 1: The detection limits (DL) of the elements in the SRM 3087A metals on filter media, as a function of the collimator diameter

Element	**DL (μg/g)**			
	10 mm	8 mm	6 mm	4 mm
V	16.30	16.80	15.03	12.95
Cr	11.23	10.75	9.39	8.33
Mn	8.91	8.50	7.96	6.42
Fe	6.61	6.80	6.30	5.39
Ni	6.85	6.60	7.00	6.08
Zn	7.00	6.87	7.06	6.50
As	3.64	5.20	4.10	3.12
Se	3.59	5.20	4.00	3.18
Pb	14.28	10.5	13.35	11.69

As expected, that detection limits of the elements were found to be lower when the diameter of the collimator was decreased. The collimator with a diameter of 4 mm was considered ideal as it showed the lowest detection limits for most of the elements and the distance between the two discs were calculated graphically and found to be 8 mm. Thus the collimator used in this study was a Pb collimator with two Mo apertures of 4 mm diameter placed 8 mm apart. The collimator was placed 3 mm in front of the detector.

Excitation voltage and anode current

The intensity, I_i, of the fluorescent radiation is a complicated non-linear function of the x-ray tube voltage, V_t, (Jenkins *et al.* 1981):

$$I_i = Ki(V_t - V_{abs})^n$$

where K = a constant
i = Anode current
V_t = Tube voltage

V_{abs} = the minimum energy required to excite the K lines of an element in a sample,

n lies in the range $1< n<2$ and depends on the anode material, on the analyte element and to some extent on the range of the tube voltage V_t.

When the tube voltage is increased, $V_t - V_{abs}$ is increased, which result in an increase of the x-ray fluorescent intensity and hence the reduction of the detection limits. However, by increasing the voltage on the x-ray tube, two effects, which are unfavorable to the detection limits, are intensified. By increasing the anode voltage, the dead time of the electronic system and the intensity of the scattered radiation are increased. The dead time causes longer measuring times and high number of coincidences, while scattered radiation causes a high background.

For the optimization of tube current and voltage, the tube voltage and current were varied while measuring the SRM 3087A metals on filter media, and the detection limits for the elements were calculated (Table 2). We observed from the results that the detection limits of the elements in the standard became lower with the increase of the tube voltage and anode current. However, the change in voltage has more effect on the detection limits than the change in current. For the same voltage, detection limits were found to vary slightly when the current was changed from 30 mA to 50 mA at intervals of 10 mA. At the same current, a big drop of detection limit was observed when the voltage was varied from 30 kV to 50 kV at intervals of 10 kV.

Table 2: Detection limits for the elements in SRM 3087A metals on filter media, as a function of tube voltage and anode current

Element	**DL (μg/g)**						
	30 kV		40 kV			50 kV	
	30 mA	40 mA	30 mA	40 mA	50 mA	30 mA	40 mA
V	30.7	28.2	18.2	18.7	20.7	14.4	14.2
Cr	20.7	23.7	12.1	11.7	15.4	8.8	9.4
Mn	17.9	16.7	9.1	9.2	12.4	8.6	7.7
Fe	14.2	14.1	8.1	7.7	9.6	6.9	6.5
Ni	16.4	14.7	8.9	8.8	9.7	7.9	7.3
Zn	15.8	14.7	9.0	9.4	8.9	8.1	7.5
As	7.4	7.4	4.0	5.0	3.9	3.7	3.9
Se	7.5	7.8	4.1	5.1	4.1	3.4	4.1
Pb	28.5	15.2	15.2	13.9	11.0	13.4	11.1

To avoid the wearing of the x-ray tube by applying unnecessary high voltage, a voltage of 40 kV was chosen. Since the detection limits for the 30 mA, 40 mA and 50 mA at 40 kV were found to be nearly the same, the lowest current of 30 mA was chosen for the routine analysis. Therefore the voltage current pair chosen was 40 kV and 30 mA.

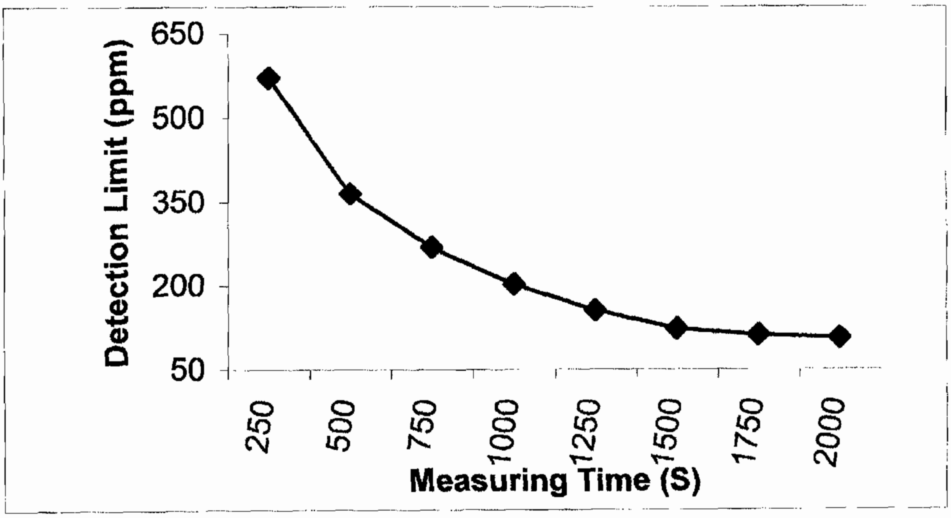

Fig. 2: Variation of detection limits with the measuring time for Titanium

Measuring time

From equation (1), the detection limit of an element is dependent on the measuring time. The higher the measuring time the lower is the detectionlimit of an element. The detection limit of Ti, Fe and Sr elements decreased with the increase of measuring time (Figs. 2-4).

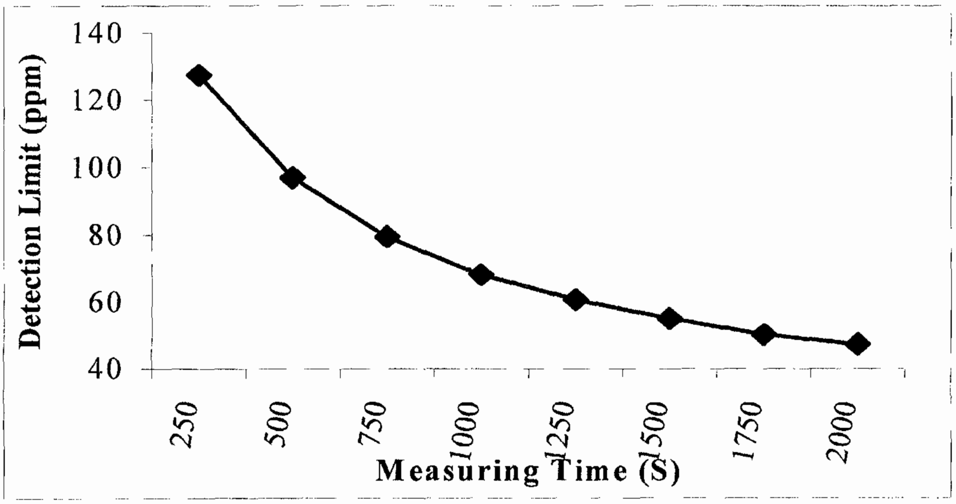

Fig. 3: Variation of detection limits with the measuring time for Iron.

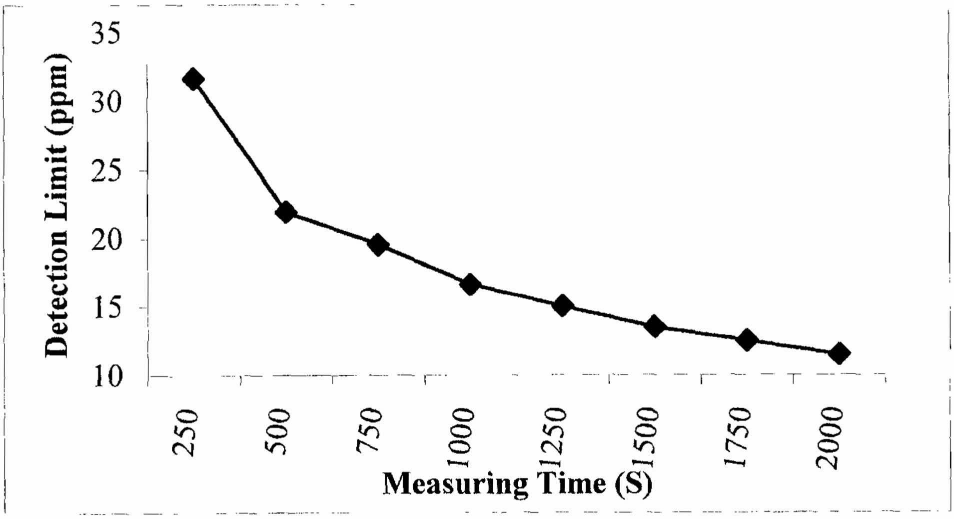

Fig. 4: Variation of detection limits with the measuring time on Strontium

Element Ti, Fe and Sr represent the low, medium and high atomic number (Z) elements respectively (Figs. 2,3,4). The detection limit for Ti were much higher than that of Fe and Sr. This could be explained by the fact that, the EDXRF system has insufficient sensitivity for low Z – elements, because the sensitivity at long wavelength is reduced by the combined effect of low fluorescence yield and strong absorption of the low energy x-ray. Furthermore, the absorption of the x-rays is high if the energy is just above the energy of the characteristic lines of the elements to be determined. Therefore Sr which has energy close to the energy of Mo x-ray lines has the lowest detection limit of the three elements.

Calibration of the EDXRF system

The samples were analyzed using an Elemental Sensitivity program in the Quantitative X-ray Analysis Software (QXAS) (Van Espen 1990). The program involves use of a calibration curve, hence the system was calibrated using single and multi element standards. The elemental sensitivity program determines the sensitivity of the characteristic lines from the standards, taking into account the absorption in the standards. Calculated sensitivities are then used to determine concentration of the element in unknown samples, again correcting for the sample self-absorption. Concentration values for elements of the unknown samples, which are not present in the standards can be obtained by interpolation or extrapolation. K_α-lines and L_α-lines are treated separately.

The accuracy of the calibration curve was checked using SRM 3087A metals on filter media. With the exception of Pb, the experimental values were in good agreement with the certified values (Table 3). The relative standard deviation from the certified values is less than 10% for most of the elements. The error in Pb could be from overlapping L_{α}lines with K_{α} lines of As.

Table 3: Element concentrations (±SD) obtained by EDXRF analysis of the SRM 3087A, metals on filter media, together with the certified values for some elements

ELEMENT	EXPERIMENTAL VALUE (g/cm^2)	CERTIFIED VALUE (g/cm^2)
V	4.76 ± 0.12	4.69 ± 0.11
Cr	1.01 ± 0.01	0.94 ± 0.02
Mn	0.93 ± 0.04	0.94 ± 0.02
Fe	2.51 ± 0.06	2.35 ± 0.05
Ni	2.46 ± 0.06	2.35 ± 0.05
Zn	9.31 ± 0.17	9.39 ± 0.22
As	4.86 ± 0.09	4.69 ± 0.11
Se	2.35 ± 0.04	2.35 ± 0.05
Ba	2.43 ± 0.18	2.35 ± 0.05
Pb	5.80 ± 0.34	3.76 ± 0.09

The detection limits (in µg/g) for some elements are V(16.8), Cr(10.8), Mn(8.5), Fe(6.8), Ni(6.6), Zn(6.9), As(5.2), Se(5.2) and Pb(10.5).

Application of the EDXRF to study heavy metal pollution of Lake Victoria

Analysis of aquatic plants gives valuable information about contamination of the surrounding water because they accumulate heavy metals from water and sediments (Lee & Keeney 1975; Khan *et al.* 1981). Water hyacinth (*Eichhornia crassipes (Mart) Solms.)* is known to be a good indicator of heavy metal pollution of the aquatic environment (Pfeiffer *et al.* 1986, Ajmal *et al.* 1988, Gonzalez *et al.* 1989). The roots of water hyacinth have been reported to be good heavy metal accumulators and could serve as a biological indicator of metal pollution in tropical aquatic ecosystem (Gonzalez *et al.* 1989, Zhu *et al.* 1999).

In the present study, optimized and calibrated EDXRF was applied to analyse water hyacinth samples from Lake Victoria for heavy metal content. The study also assessed the pollution level and locate sources.

Study area

Lake Victoria lies within latitudes 1° N and 4° S and longitudes 31°E and 35°E. The lake is shared by the three countries of Tanzania, Uganda and Kenya. On the Tanzania side, Lake Victoria serves a population of about 5 million people and is the main source of water for domestic and industrial consumption, transportation, recreation, agriculture and fishing. Domestic sewage and other wastes are discharged into the lake through main sewage trenches, septic tanks and old leaking pipes from domestic and public facilities. Small-scale mining and gold processing activities in the lake zone are predicted to introduce several hazardous heavy metals, including mercury, to the lake by way of runoff. Industries built along the shore discharge chemical wastes containing heavy metals and organochlorides. During the rainy seasons some of the agrochemicals used in crop production are swept by rainwater into the lake through its major rivers such as Kagera, Mara and Kilondo. The harbour and fishing settlements along the shore introduce dirt oil and other wastes into the lake.

Sampling

Twenty samples of water hyacinth were collected in three zones, along the shore of Lake Victoria. Seven samples were collected from Zone 1, eight samples from zone 2 and five samples from zone 3 (Fig. 5). Special attention was given to the industrial discharge points, streams and open channels influenced by domestic sewage.

Zone 1: Mwanza south

In Mwanza South, samples were collected near a fish processing industry, the Lake soap industry, animal feed industry, two oil depots (Caltex and B.P.) and around the Tanzania Railways Co-operation marine division.

Zone 2: Mwanza central

In Mwanza Central, samples were collected in the Mirongo river close to the outlet of the central sewage system and close to a sewage system outlet near Mwaloni area, at a Private ferry station near Makongoro road and from an unnamed sewage system outlet near Nera road.

Zone 3: Mwanza north

Here the samples were collected near the East African Tanneries factory, Breweries factory, close to the fish and printing industries and at a remote area in Buja.

Sample preparation

Water hyacinth samples were washed using distilled water to get rid of external dirt then subdivided into roots and shoots. Jana (1988), Chocooj *et al.* (1993) and Mugasha (1995) did research to compare the accumulation of heavy metals (Pb, Cr and Hg) in the roots and shoots of water hyacinth and observed that a large percent was retained in the root system and based on their observation, we used the roots of water hyacinth in our present study. The roots were oven dried for 48 hours at temperatures of about 45°C. The dried roots were crushed into small particles and then pulverised into a powder using an electric grinder. When it was necessary, additional manual grinding was done to obtain finer powder. Pellets of about 1 mm thick, 25 mm in diameter and mass of 1.5 g were made out of the powder using a hydraulic press which compacted the powder between two polished steel discs at a pressure of about 1.5×10^8 N/m^2.

The water hyacinth samples were susbsequently analyzed using the EDXRF spectrometer with a Mo x-ray tube and a Mo secondary target operated at 40 kV and 30 mA. The measuring time for one spectrum was about 2000 seconds, which was enough to obtain good statistics. The characteristic fluorescent x-rays were detected by a Si(Li) detector and identified using the AXIL software described by Van Espen (1990).

RESULTS AND DISCUSSION

There was much of variation in the content of element between the three zones of the Mwanza mucinipality (Figs. 5,6,7).

Mwanza south

The concentrations of the elements found in this zone varied widely between samples (Table 4). Sample P1 from a sewage system outlet had the highest concentrations of Ti, Cr, and Ni and significantly high concentrations of Mn, Fe and Zr. Sample P3, which was collected around the water pump adjacent to an industrial complex, had the highest concentrations of Cu and Zr and significantly high concentrations of Ti, Cr, Mn, and Fe. The highest concentrations of Fe and Zn were found in sample P2, which was collected near the fish processing industry. Samples P5 and P6 collected adjacent to the lake soap, animal feed and fish processing industries had high concentrations of Pb. Nickel was detected in samples P1, P3 and P6. Chromium and Co were found only in samples P1 and P3, while Scandium was found in samples P2 and sample P4 collected from the lakeshore. However, Co and Sc showed high standard deviations, that indicate low concentration.

Table 4: Concentrations (±SD) of elements found in the Water hyacinth samples collected at Mwanza South

ELEMENT	P1 µg/g	P2 µg/g	P3 µg/g	P4 µg/g	P5 µg/g	P6 µg/g	P7 µg/g	MEAN µg/g
K	37420	36290	30480	67620	34460	86330	39010	47373
	±800	±1000	±100	±1000	±900	±2000	±800	±900
Ca	40500	77720	48180	71380	40870	75050	70470	60586
	±1000	±2000	±1000	±1000	±900	±2000	±1000	±1300
Sc	-	1769	BDL	1821	-	-	-	512
		±500		±600				±200
Ti	5789	3891	5191	923	2026	1222±	1311	2908
	±200	±200	±200	±100	±200	100	±200	±200
Cr	691	-	178	-	-	-	-	124
	±60		±40					±10
Mn	21600	8805	29860	2671	31730	8466	13850	16712
	±400	±200	±500	±80	±600	±200	±300	±300
Fe	75130	93820	57810	20000	28210	28790	14920	45526
	±1000	±2000	±1000	±400	±500	±600	±300	±800
Co	588	BDL	445	BDL	BDL	BDL	BDL	652
	±157		±125					±20
Ni	437	-	318	-	-	64 ±20	-	117
	±20		±30					±10
Cu	161	180	2444	-	BDL	BDL	BDL	397
	±40	±40	±90					±20
Zn	2954	4689	2635	3433	2198	3746	1628	3040
	±40	±80	±40	±50	±30	±60	±20	±50
Rb	474	304	441	192	316	165	220	302
	±10	±8	±9	±5	±8	±5	±5	±10
Sr	1925	3002	1947	1265	1516	1814	2834	2043
	±30	50	±40	±20	±30	±30	±50	±40
Y	80 ±5	22 ±5	52 ±6	-	13 ±4	-	-	24 ±3
Zr	1935	1567	2165	745	308	650	626	1142
	±100	±100	±200	±70	±50	±90	±80	±100
Pb	1100	503	384	40	948	729	47±1	535
	±60	±20	±20	±5	±50	±40		±30

BDL = below detection limit

- = not detected

Figure 5 shows a representative spectrum of the water hyacinth sample collected from Mwanza South zone. The peaks corresponding to the elements present in the water hyacinth sample collected from Mwanza South zone.

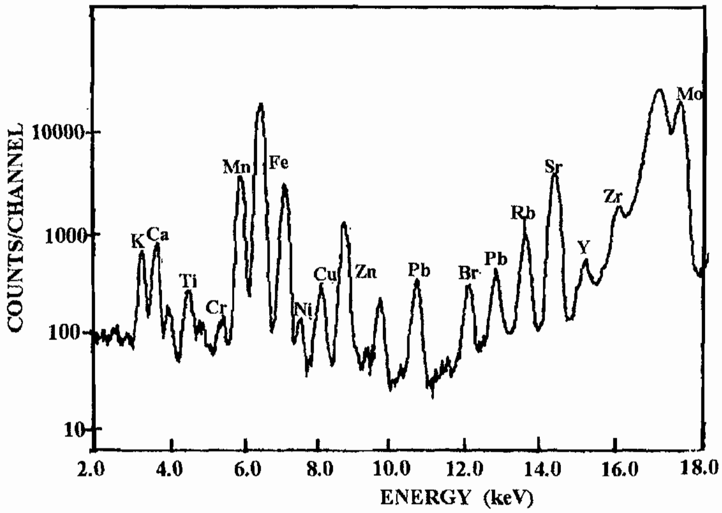

Fig. 5: A typical spectrum of the water hyacinth sample collected from Mwanza South, Tanzania.

Mwanza central

Samples collected near the outlets of sewage systems P9 (River Mirongo), P13 (between Kirumba and Mwaloni) and the sewage system at Mwaloni (P14), had the highest concentrations of Ti, Mn, Fe and Co and significantly high concentrations of Zn, and Pb (Table 5). Samples collected at the ferry station (P11) and the boat harbour of Mwaloni (P15) had the highest concentrations of Zn and Pb. The source for Pb at ferry and boat harbour is likely to be emissions from boat engines which were stationed in these areas, while Pb found in the sewage systems is likely to be from the ceramic dishes and cups and from cosmetic hair dyes and eyeliners (Berman 1980). Element Ti could have been from paints, enamels, ceramics and plastics and from stain remover in laundry. The iron likely came from metal works and the Mn could have came from varnishes and oil (Berman 1980). Zinc seen in these samples could have came from the metal plating and steel works (Harrison 1983). Samples P11 and P12 showed the highest levels of Cu. This might be related to the fungicide and insecticides used in the flower nursery found near the sampling station. Vanadium was only detected in sample P9 collected near river Mirongo, which collects its effluents from Mwanza textile industry, Mwatex Ltd. It is known that Vanadium is essential in the dyeing and printing of cotton and silk (Berman 1980).

Table 5: The Concentrations (±SD) of elements found in water hyacinth samples collected at Mwanza central zone

ELEMENT	P8 µg/g	P9 µg/g	P10 µg/g	P11 µg/g	P12 µg/g	P13 µg/g	P14 µg/g	P15 µg/g	MEAN µg/g
K	5834 ±300	15040 ±500	56830 ±1000	42230 ±900	31840 ±500	36680 ±900	24120 ±600	32440 ±900	30379 ±700
Ca	12080 ±500	46620 ±1000	71960 ±2000	54730 ±1000	57180 ±1500	35610 ±800	13280 ±600	53000 ±1000	43058 ±100
Sc	-	-	1575 ±50	-	BDL	-	-	-	196 ±10
Ti	734 ±100	4013 ±200	3772 ±200	5396 ±200	2804 ±200	7622 ±300	4370 ±200	4630 ±200	4168 ±200
V	-	580 ±200	BDL	BDL	-	-	297 ±70	-	109 ±30
Cr	-	-	871 ±50	864 ±60	857 ±50	-	-	-	324±20
Mn	1567 ±50	3628 ±90	27580 ±500	9260 ±200	16870 ±300	38430 ±700	4307 ±100	3603 ±80	13155 ±300
Fe	3268 ±90	142290 ±2000	47600 ±800	77020 ±1000	51440 ±900	84170 ±1000	34890 ±600	60460 ±1000	62642 ±900
Co	-	660 ±20	533 ±90	557 ±200	BDL	577 ±200	249 ±80	479 ±100	382 ±90
Ni	-	-	262 ±20	469 ±30	431 ±30	-	-	-	145 ±10
Cu	-	BDL	BDL	486 ±50	471 ±40	99 ±30	-	346 ±100	175 ±30
Zn	43 ±6	2710 ±40	1671 ±20	2265 ±30	3660 ±60	1872 ±30	741 ±8	4217 ±300	2147 ±60
Rb	99 ±3	281 ±7	436 ±10	587 ±10	486 ±10	845 ±20	667 ±10	621 ±10	503 ±10
Sr	720 ±10	2029 ±40	1672 ±30	1966 ±40	2369 ±40	1388 ±30	483 ±9	2007 ±40	1579 ±30
Y	7 ±2	109 ±5	41 ±5	74 ±4	27 ±4	191 ±6	81 ±3	54 ±4	73 ±4
Zr	491 ±40	1587 ±90	1749 ±100	1959 ±100	1195 ±90	2368 ±100	1288 ±50	1986 ±100	1577 ±80
Pb	-	572 ±30	395 ±20	755 ±40	447 ±20	641 ±30	187 ±5	663 ±30	458 ±20

BDL = below detection limit
- = not detected

Mwanza north

Water hyacinth samples collected at Mwanza North show fewer numbers of elements than that collected from the other zones (Table 6). Lead was not found in any sample collected from Mwanza North. The zone had tannery, breweries and printing industries. Their operations are reflected by the presence of Cr, Co and Ni in all samples collected in this zone. Chromium is essential in the tanning of leather, cobalt is used as a foam stabilizer in the brewing of malt beverages (Berman 1980) and nickel is used in printing (Harrison 1983).

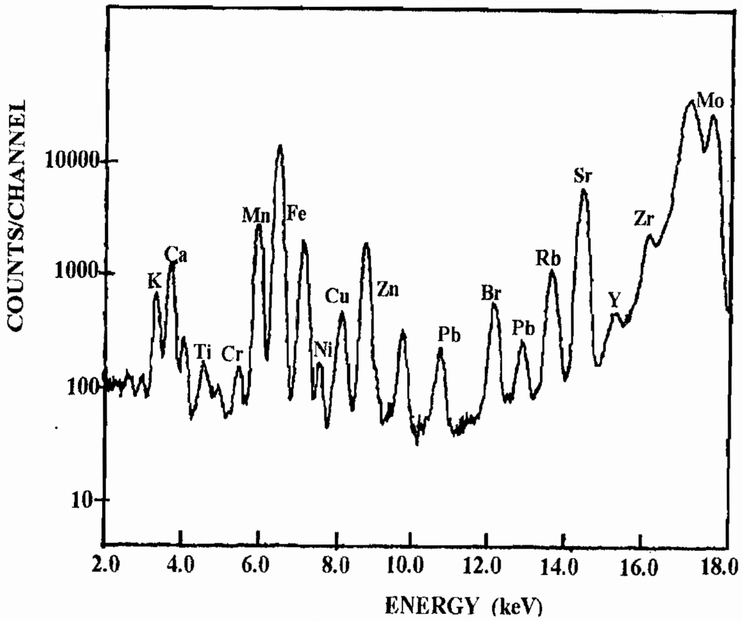

Fig 6: A typical spectrum of the water hyacinth sample collected from Mwanza Central zone, Tanzania.

The presence and concentration of elements in water hyacinth samples reflect the nature of the activities done within the area where the samples were collected. Mwanza north had the highest concentrations of Cr, Co and Ni, which reflect the operations of tannery, breweries and printing industries respectively near the sampling stations. The industrial area (Mwanza south), Municipal sewage system and the harbour (Mwanza central) likely contributed more to the Ti, Mn, Fe, Cu, Zn, Zr and Pb (Fig. 6). Rb, Sr and Y in the whole Mwanza municipality was persistently low which indicates a common natural source.

It is important to note that the maximum concentrations of Cr, Mn, Fe, Ni, Cu, Zn and Pb found in Lake Victoria are far higher than those reported from Yamuna River (India), (Ajmal *et al.* 1985), Kali Nadi U.P. (India) (Ajmal *et al.* 1988) and from River Sagua la Grande (Cuba) (Gonzalez *et al.* 1989) (Table 7). This may indicate that Lake Victoria is heavily contaminated with heavy metals.

Table 6: The Concentrations (±SD) of elements found in water hyacinth samples collected at Mwanza north zone, Tanzania

ELEMENT	P16 µg/g	P17 µg/g	P18 µg/g	P19 µg/g	P20 µg/g	MEAN µg/g
K	50420 ±1000	4611 ±300	27000 ±700	7500 ±400	26920 ±600	23290 ±400
Ca	42640 ±1000	10180 ±500	29160 ±700	12880 ±400	45560 ±1000	28084 ±800
Ti	5312 ±200	460 ±100	6445 ±200	4646 ±200	2198 ±200	3812 ±200
Cr	1426 ±70	118 ±30	443 ±40	95 ±30	1211 ±60	659 ±50
Mn	14660 ±300	1521 ±50	11880 ±200	4816 ±100	9834 ±200	8542 ±200
Fe	57220 ±1000	3136 ±80	31800 ±600	19210 ±400	19290 ±400	26131 ±500
Co	646 ±100	68 ±20	269 ±90	252 ±80	165 ±50	280 ±70
Ni	645 ±30	50 ±10	165 ±20	38 ±10	493 ±30	278 ±20
Cu	598 ±30	-	–	–	166 ±20	120 ±10
Zn	3592 ±60	51 ±7	191 ±3	301 ±2	186 ±5	864 ±20
Rb	499 ±10	102 ±3	292 ±6	196 ±5	264 ±6	271 ±6
Sr	1642 ±30	746 ±3	12 ±20	96 ±20	16056 ±30	3710 ±20
Y	62 ±4	–	36±3	23 ±3	–	24 ±2
Zr	1580 ±90	364 ±30	744 ±50	754 ±60	914 ±90	871 ±60

BDL = below detection limit
- = not detected

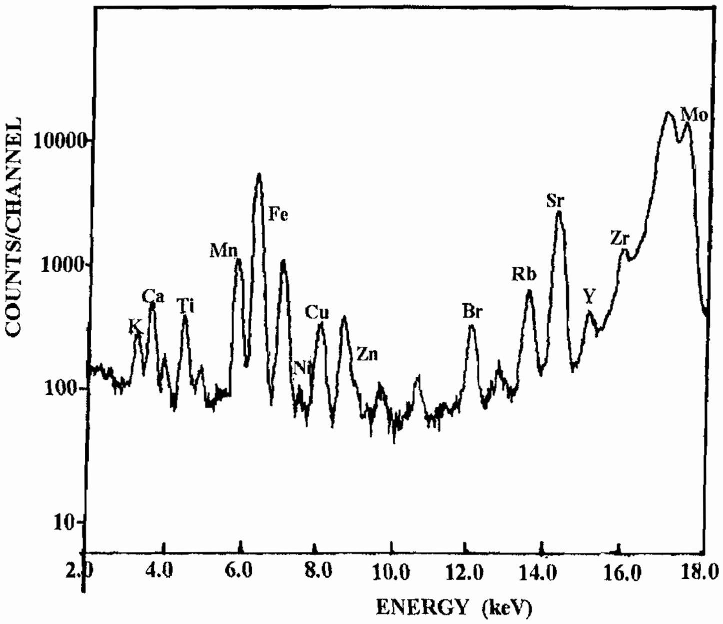

Fig 7: A typical spectrum of the water hyacinth sample collected from Mwanza north zone, Tanzania. Note that there are fewer elements than was the cases for Mwanza south and central.

Table 7: Maximum concentrations of some of the heavy metals in the water hyacinth from Lake Victoria (Tanzania) and from other rivers around the world

	Cr μg/g	Mn μg/g	Fe μg/g	Ni μg/g	Cu μg/g	Zn μg/g	Pb μg/g	Reference
River Yamuna (India)	65	1443	1633	83	114	366	30	Ajmal et al., (1985)
River Kali Nadi U.P. (India)	5	111	1235	12	19	98	6	Ajmal et al., (1988)
River Sagua la Grande (Cuba)	38	12000	6600	----	55	150	51	Gonzalez et al., (1989)
Lake Victoria (Tanzania)	1426	38430	93820	645	2444	4689	1100	Present Study

CONCLUSION

The EDXRF system of the Physics Department, University of Dar es Salaam was optimized, calibrated and used to study water hyacinth samples from Lake Victoria. Several factors, which influence the detection limits, were experimented and their optimal conditions recorded and used for the analysis of metal pollution.

The study found, as expected, that the detection limits become lower when the aperture of the collimator was reduced. Out of the four collimators used in this study, the collimator with the lowest aperture of diameter 4 mm gave the best results. However, the study found that a Pb collimator might introduce unwanted Pb x-ray lines into the spectrum, hence, the Pb collimator with a Mo aperture was constructed and used instead. A collimator with double discs was found to give better results than a collimator with a single disc. For the 4 mm aperture collimator used in this study, the optimal distance between the two discs was graphically found to be 8 mm. The optimal sample-detector distance was found to be 3 mm.

The study found that changes in tube voltage might have more effect on the detection limits of the elements than change in anode current. However, both the tube voltage and the anode current lower the detection limits of the elements when they are increased. The optimal pair for the tube voltage and anode current was found to be 40 kV, 30 mA. With this set of parameters, the optimal measuring time was found to be 2000 seconds.

High concentrations of toxic elements Pb (1100 µg/g), Cr (1426 µg/g), Zn (4689 µg/g), Ni (645 µg/g), Cu (2444 µg/g), Mn (38450 µg/g) and Ti (7622 µg/g) were detected in the roots of water hyacinth samples from Lake Victoria. Water hyacinth from the industrial area and those from sewage discharge points had higher concentrations of the metals than that from less polluted areas. A follow-up study localizing the source of heavy metal pollution so as to enhance the statistical significance of heavy metal pollution in Lake Victoria is recommended. The differences between concentrations of heavy metals from water hyacinth found in this study and that from water hyacinth reported elsewhere are big. Measures to control the pollution of the lake should be taken otherwise the health of human population and the biodiversity of the lake might be in danger.

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