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Heavy metal assessment and water quality values in urban stream and rain water

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ABSTRACT: Water quality monitoring in developing countries is inadequate, especially in stream water affected by urban effluents and runoff. The purpose of this study was to investigate heavy metal contaminants in the Nakivubo Stream water in Kampala, Uganda. Water samples Nakivubo Channelized Stream, tributaries and industrial effluents that drain into the stream were collected and analysed for the total elemental concentration using flame atomic absorption spectrophotometer. The results showed that: 1) the wastewater was highly enriched with lead and manganese above the maximum permissible limit; 2) the levels of dissolved oxygen were below the maximum permissible limit, while the biological oxygen demand was above the maximum permissible limit. All industrial effluents/wastewater were classified as strong (> 220 mg/L). Factor analysis results reveal two sources of pollutants; 1) mixed origin or chemical phenomena of industrial and vehicular emissions and 2) multiple origin of lead (vehicular, commercial establishment and industrial). In conclusion, Nakivubo Channelized Stream water is not enriched with heavy metals. These heavy metals (lead, cadmium and zinc) were rapidly removed by co-precipitation with manganese and iron hydroxides and total dissolved solids into stream sediments. This phenomena is controlled by pH in water.

Keywords: *Co-precipitation; Factor analysis; Industrial emission; Nakivubo; Water quality*

INTRODUCTION

Heavy metal contamination of stream and river water ecosystem is a worldwide environmental problem. Trace amounts of heavy metals are always present in fresh waters from the weathering of rocks and soils (Muwanga, 1997; Anderson, 2003; Babel and Opiso, 2007; Samarghandi *et al.*, 2007; Igwe *et al.*, 2008; Al-Juboury, 2009). Recently, water quality monitoring has become a matter of concern in stream and river water systems affected by careless disposal of urban effluents. Runoff, atmospheric deposition and domestic and industrial effluent discharges are the major sources of aquatic pollution (Wasswa, 1997; Linnik and Zubenko, 2000; Campbell, 2001; Lwanga *et al.*, 2003 and Lomniczi *et al.*, 2007) and physico-chemical characteristics such as dissolved oxygen and the pH of aquatic ecosystems may determine stream water ecosystem integrity. Monitoring of stream water physico-chemical characteristics and heavy metal concentration is necessary to establish the levels of contamination in wastewater. With increasing urbanisation and industrialization, there has been a rapid increase in industrial effluent discharge into the stream water, leading to increased pollution load. In aquatic eco-systems, trace elements may be immobilised within the stream water and may involve complex formation and co-precipitation as oxides and hydroxides of Fe, Mn or may occur in particulate form (Awofolu *et al.*, 2005; Mwiganga and Kansiime, 2005; Nyangababo *et al*, 2005b; Srivastava *et al.*, 2008).

The Nakivubo Channelized Stream is the major recipient of runoff and a surrogate end point for organic substances of industrial and domestic effluents (Kansiime *et al.*, 1995; Sentongo, 1998). The Nakivubo channel is increasingly being polluted with direct

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discharge of raw industrial effluent, untreated sewage and wastewater from commercial, industrial and domestic establishments. The Nakivubo Channelized Stream is important because it was constructed primarily to minimize flooding in the city, but is also being used for fishing, farming, washing and as a source of drinking water. The amount of point source pollutant effluents for this channel may affect the Ggaba water treatment plant quality intake since it is only 4 km away (Sentongo, 1998). In the upstream, the flow rate is very low and water in the channel has a dark colour characterized by bad odour of decaying organic matter during dry periods. The smell is augmented by sewage effluent discharge from the National Water and Sewage Corporation (NWSC) plant, city abattoir and residential and commercial establishments into the channel. The objects of the present work were to; 1) assess heavy metal concentration and contamination in the Nakivubo Channelized stream water 2) investigate the relationship among heavy metals and physico-chemical characteristics and 3) determine the common origin of the contaminants using Factor and Cluster analyses. This study was conducted during August, 2008 to November 2009, along the Nakivubo Channelized stream, Kampala Uganda.

MATERIALS AND METHODS

Study area and sampling sites

The Nakivubo Channelized Stream, originating from

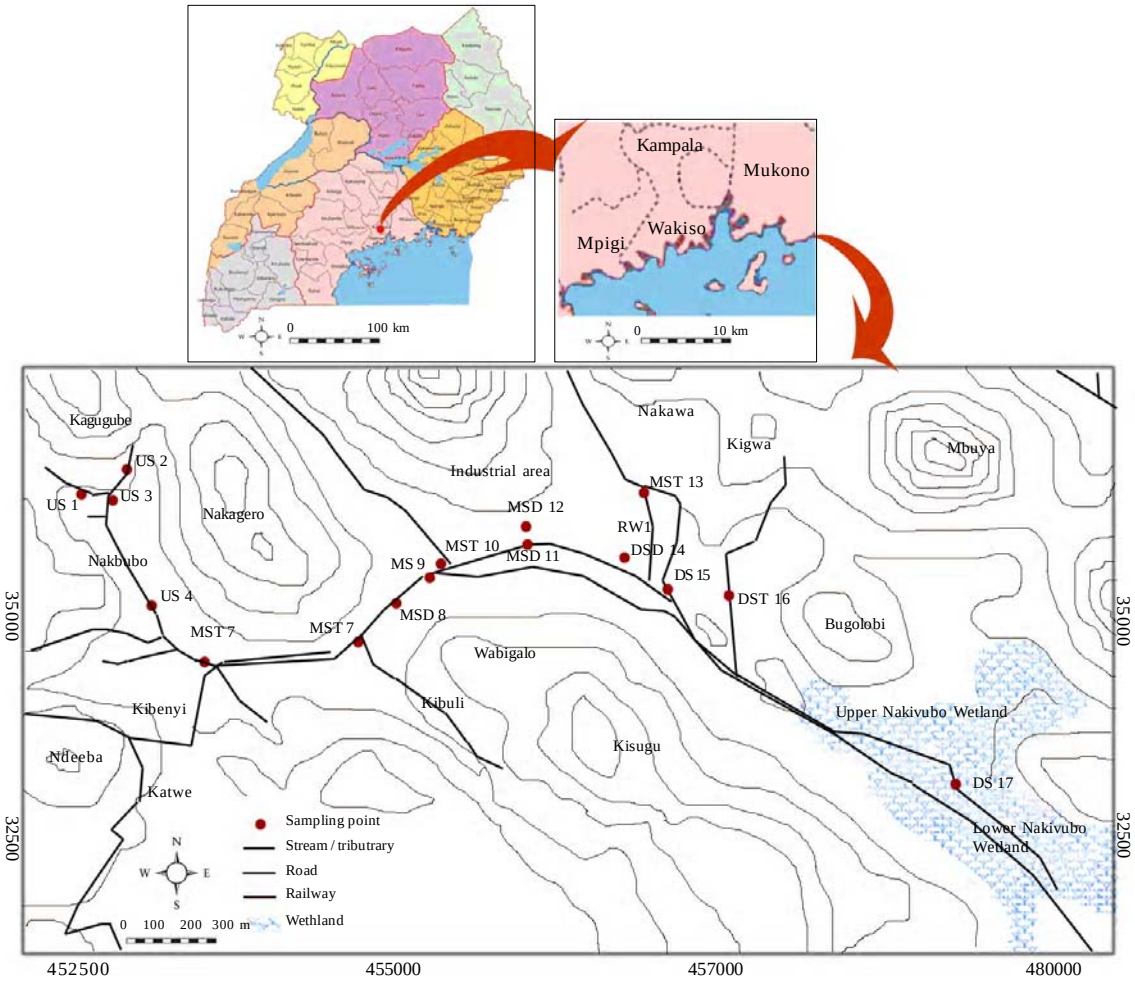

Fig. 1: Map showing the locations of the sampling sites along the Nakivubo Channelized Stream, Kampala, Uganda

Makerere hill has two sources that merge at Kisekka market. The stream is 12.3 km long, 2.3 km of which is the Channel length of the upper and lower Nakivubo wetlands. The Nakivubo Channelized Stream is feed by six streams and divided into three sections namely; upstream (US01 – MD05) characterised by commercial establishments, midstream (MD05 – DS15) characterised by commercial and industrial establishment and downstream (DS15 and beyond), characterised by the Nakivubo wetland (Table 1). The study area is located 0°15'N and 32°30'E, 45 km north of the Equator and 8 km from Lake Victoria, with a total area of 190 km^2 (Fig. 1). Samples were collected from the middle of the stream that flows and drains through Kampala City. Nakivubo swamp soils are characterised by alluvial and lacustrine sands, silt and clay. The alluvial soils in the upper layers are composed of semi-liquid organic material, reddish ferruginous loams and clays attributed to organic decomposition and runoff (Kansiime *et al.*, 1995). Part of the industrial area soils are composed of shales, phillites and schists with a mixture of alluvial and lacustrine sand, silt and clay.

Water sampling and chemical analysis

A modified bulk sampler (Fig. 2) consisting of a polyethylene funnel with 20.8 cm opening, connected to a 5 L polyethylene conical flask was used in collection of rain water. The funnels and conical flasks were wrapped in an aluminium foil to avoid algal growth on the bulk precipitate and placed 1.5 m above the ground (Nyangababo *et al*, 2005a). The bulk precipitation collected in one-month was poured in one flask and mixed thoroughly to homogenize the precipitate from the five flasks. Duplicate samples of 500 mL were collected and transported to the laboratory in an ice box at 4 °C and the precipitate was first filtered through a 0.45 µm filter and preserved with nitric acid. Heavy metal elements were then analyzed by direct aspiration of the sample solution into a Perkin-Elmer model 2380 Flame atomic absorption spectrophotometer. Stream water samples were collected over a one year period along the Nakivubo drainage system and Watindo Stream as described by Muwanga (1997). Watindo Stream was chosen to be outside the study area and therefore regarded as unpolluted. The samples were taken from the middle of the stream carefully to avoid contamination using sample bottles. Sampling bottles were washed with dilute nitric acid, rinsed

Table 1: Location and description of activities/establishment

Site	Code	GPS readings		Activity/ Establishment
Upstream		Lat.	Long.	
Agakhan high School Bridge	US01	0.3221	32.5693	Car washing Bay, fish factory, gas/fuel station, residential, bus parking yard, seepage from walls
Bativa hotel Kivulu Bridge	US02	0.324	32.5726	Car washing Bay, gas/fuel station, slum residential and commercial and seepage
Kiseka market bridge	US03	0.3215	32.5716	Car washing Bay, garage, commercial and seepage
Nakivubo stadium Bridge	US04	0.3169	32.5723	Recreational, commercial, market, vehicle traffic, Bus park, gas/petro station, and seepage
Midstream				
Fire brigade bridge	MS05	0.3129	32.5743	Commercial , recreational, vehicle traffic, Bus park, gas/petro station, cement stores , Katwe metal works and fabrications and seepage
6th street bridge-Mukwano	MS09	0.3099	32.5891	Commercial, Oil storage in vicinity, vehicle traffic, gas/petro station, seepage, industries
Downstream				
5th street bridge	DS15	0.3222	32.6093	Industries, vehicle traffic, sewerage plant, seepage, garages, metal fabrication, petro station , residential
Luzira Culvert	DS17	0.3188	32.6169	Industries, cultivation, fishing, residential
Tributaries				
Kayunga stream	MT07	0.3081	32.5782	Solid waste dump sites, horticulture, recreational, slum and residential, vehicle traffic, gas/petro station
Kitante stream	MT10	0.3099	32.5891	horticulture, recreational, residential and commercial, vehicle traffic, gas/petro station
Lugogo stream	MT13	0.3191	32.6011	Vehicle traffic, commercial, residential and industrial, electric station, horticulture, carpentry works, pole treatment and seepage
Kibira road stream	DT16	0.3142	32.611	Battery , plastic and paper factory, industries and gas/petro station

with deionised water and again washed three times with the stream water before they were filled. For heavy metal analysis, a 500 mL bottle of linear polyethylene was used to collect water samples, filtered (using 0.45µm pore size) and three drops of concentrated nitric acid added for preservation. Also, 1 L bottle to collect water samples was used for determination of physico-chemical characteristics (total suspended solids and biological oxygen demand). All were stored in an ice box at 4°C and transported to Geology Laboratory at Makerere University and National Water and Sewerage Corporation central Laboratory at Bugolobi, respectively for analysis. Other physico-chemical characteristics such as dissolved oxygen, electrical conductivity, pH, temperature and total dissolved solids were determined on site using potable meters. The elements were then analyzed by direct aspiration of the sample solution into a Perkin-Elmer model 2380 flame atomic absorption spectrophotometer (AAS) after calibration with suitable elemental standards at close intervals.

Assessment of stream water contamination

Total suspended solids (TSS); Wastewater TSS classification consists of three classes (0-220 mg/L) ranging from weak to strong (< 100 mg/L) weak (100 – 220 mg/L) medium and strong wastewater (> 220 mg/L), Akan *et al* (2008).

Statistical analysis

Analysis of variance (ANOVA): ANOVA was employed to determine whether groups of variables have the same means on data that are continuous or normally distributed and with homogeneous variance. Additionally, it was employed to assess the relationship between heavy metal concentrations and their elemental interaction between sections of the stream.

Correlation analysis: Pearson correlation's correlation analysis was adopted to analyse and establish inter-metal relationship and physico-chemical characteristics of the stream water.

Cluster analysis (CA) and Factor analysis (FA): CA was performed using Minitab Release 14 or 15 to classify elements of different sources on the basis of their similarities using dendrogram and to identify relatively homogeneous groups of variables with similar properties. FA was employed on the variables that are correlated to isolate or determine specific factors that are associated with such groupings of metal concentration to establish their origin. The data was standardized to give a normal distribution with a mean of 0 and a variance of 1. Sample means were standardized by subtracting the mean of their distribution and dividing by standard error (SE) or square root of the variance.

RESULTS AND DISCUSSION

Water chemical characteristics

Mean concentration of trace metals and physico-chemical parameters are given in Table 2. The pH ranged from 6.30 to 9.83 for the Nakivubo Channelized

Fig. 2: Modified bulk sampler used in collection of rain water samples

Stream suggesting a slightly acidic to alkaline pH which fell within the range of surface water under natural conditions (5.0 to 8.6), the value recorded at 6th Street Bridge Mukwano fell well above the upper end of the range considered as normal, attributed to industrial wastewater outfall from Mukwano industreis. Dissolved oxygen (DO) ranged form 0.00 to 6.69 mg/L Nakivubo Stream, 0.0 to 7.39 mg/L tributaries, 0.0 to 4.4 mg/L, industrial discharge outfall and 0.40 to 5.48 mg/L. Water was poorly aerated as indicated by very low dissolved oxygen in stream water which generally decreased downstream. WHO (2008) recommends 5.0 µm/L and above of DO but all stream water samples were bellow maximum permissible limit except Watindo Stream water which was relatively good. Dissolved oxygen below 5.0 mg/L may suggest aquatic contamination of such stream waters. Anoxic conditions are attributed to biochemical processes, oxidation of the substances, or decomposition of organic matter. Increased total dissolved solids (TDS) and biological oxygen demand (BOD) may suggest increased organic matter (OM) within the stream from industrial discharge, wastewater and effluents and ability of self-purification (Phiri *et al*, 2005; Akan., *et al*, 2007 and Akan *et al*, 2008). City Abattoir (105-395 mg/L), peacock paint factory (14-2150 mg/L) and Sadolin paint factory/Meat parker outlet (214-3725 mg/L) are the biggest contributors of total suspended solids (TSS) and hence registered the highest BOD (5.6-1304 mg/L, 16.3-1806 mg/L and 137.2-3192 mg/L, respectively) and EC. This phenomenon indicated industrial emission into the Nakivubo Channelized Stream as the major source of contaminants.

The mean value of BOD at sites US01, US04, MS05, MS09, DS15, DS17, DST16 and all industrial discharge outlets to Nakivubo Channel exceeded the National Environment Management Authority (NEMA) critical level of 50.0 mg/L maximum permissible limits in effluent and wastewater (Table 2). Also, the mean value of total suspended solids at sites US01, US02, US04, MS05, DS15, CT03 and all industrial discharge outlets exceed the maximum permissible limit of 100 µm/L in wastewater or effluents and is classified as strong wastewater at Peacock paint factory, Sadoline paint factory and NWSC plant (> 220.0 mg/L) outfall. Electric conductivity (EC) was highest at industrial discharge outfall wastewater followed by tributaries and ranged between 397.0 and 1884.0 µs/cm and 208.0 to 961.0 µs/cm, respectively whereas sadoline paint factory ranged between 208.0 and 961.0 µs/cm). EC showed a trend of gradual increase downstream, suggesting increased dissolved elements/substances to Murchison Bay into Lake Victoria. These results are consistent with those of Kar *et al*., (2008). However, Total dissolved solids (TDS) were within National Electrical Manufacturers Association regulations for maximum permissible limit of discharge of wastewater and industrial effluents (1200 mg/L and 2000) (NEMA, 2006; WHO, 2008).Results of heavy metal concentration in stream water are shown in Table 3. Heavy metal concentrations in Nakivubo Channelized Stream water ranged from 44 ± 18 to 129 ± 70 µm/L Pb; 3 ± 1 to 9 ± 4 µm/L Cd; 8 ± 2 to 44 ± 35 µm/L Cu; 26 ± 6 to 59 ± 9 µm/L Zn; 505 ± 495 to 1035 ± 65 µm/L Mn and 300 ± 200 to 1450 ± 550 µm/L Fe. Stream water samples at Kiseka Market Bridge were the most contaminated by Pb, followed by the Luzira Culvert along the Nakivubo Channelized Stream. Generally, Pb concentration increased downstream but with the highest contributions from industrial discharge outfall.

The concentration of Pb exceeded the WHO (2008) for drinking water at most of the sites and NEMA, (2006) maximum permissible limit of discharge of wastewater into the environment (100 µm/L) at Kiseka Market, Kibira road tributary and Sadoline paint factory, However, Pb heavy metal concentrations at all sites exceeded 25 µm/L criterion for the protection of aquatic life. Total heavy metal content in stream waters along the tributaries to Nakivubo Channel ranged from 63 ± 24 to 106 ± 27 µm/L Pb; 3 ± 2 to 6 ± 2 µm/L Cd; 2 ± 4 to 8 ± 4 µm/L Cu and 51 ± 11 to 144 ± 24 µm/L Zn. Stream water along Kibira Stream tributary was the most contaminated with Zn, followed by Kitante stream and Lugogo. Lugogo stream water had the highest concentration of Cd (13 ± 6 µm/L) and Cu (18 ± 12µm/L) followed by Kibira and Kayunga streams Cd (64 ± 20 µm/L) and Kitante Cu (16 ± 7 µm/L). The concentration of Cd exceeded WHO (2008) maximum permissible limit of 3 µm/L in wastewater. Heavy metal contents in stream waters at industrial discharge outlets range from 69 ± 25 to 113 ± 31 µm/L Pb; 4 ± 2 to 12 ± 5 µm/L Cd; 8 ± 3 to 18 ± 4 µm/L Cu; 51 ± 11 to 144 ± 25 µm/L Zn; 165 ± 35 to 2400 ± 700 µm/L and 600 ± 100 to 3050 ± 550 µm/L Fe. The range obtained from discharge outlets were within the NEMA standards for discharge of effluents and wastewater critical levels for Cd, Cu and Zn, except Pb which exceeds the limit of 100 µm/L as the maximum contaminant level at Sadoline paint

Table 2: Mean physicochemical characteristics of stream water samples from Nakivubo Channalized Stream, tributaries, industrial effluents and Watindo Stream (n=16)

	Temp (°C)			pHw			TDS (mg/L)			TSS (mg/L)			EC (µs/cm)			DO (mg/L)			BOD (mg/L)		
Site	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min	Max.	Mean	Min	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min	Max.
US1	26.93	22.90	30.20	7.11	6.30	7.83	235.06	215.00	271.00	176.13	16.00	850.00	470.88	432.00	544.00	2.51	0.48	4.28	62.33	11.20	176.90
US2	26.58	22.50	30.10	7.07	6.55	7.97	178.81	145.00	255.00	118.31	5.00	733.00	356.75	299.00	502.00	3.32	0.00	6.69	36.08	5.60	188.60
US3	27.79	23.40	31.20	7.28	6.92	7.99	236.88	187.00	359.00	82.81	19.00	185.00	477.13	377.00	763.00	2.55	0.63	4.72	44.54	10.92	145.60
US4	27.51	23.30	30.30	7.18	6.30	7.89	251.00	114.00	298.00	195.13	48.00	357.00	471.52	5.30	618.00	1.80	0.00	3.26	166.97	58.52	952.00
MS5	27.13	24.10	29.60	7.19	6.84	7.94	298.66	3.57	433.00	278.50	109.00	1400.00	596.32	7.16	867.00	1.40	0.00	3.96	136.90	11.20	351.68
MS9	25.79	21.80	28.30	7.78	6.94	9.83	264.56	178.00	463.00	54.44	12.00	161.00	534.75	344.00	923.00	1.48	0.00	3.50	83.59	7.70	672.00
DS15	24.49	22.50	26.10	7.55	7.17	8.22	357.94	190.00	443.00	172.94	29.00	410.00	736.99	540.00	892.00	0.77	0.00	2.08	140.43	7.14	560.00
DS17	22.87	21.40	24.80	7.05	6.70	7.89	334.69	236.00	426.00	86.59	9.40	194.00	667.31	473.00	807.00	1.02	0.00	2.15	71.75	23.52	280.00
MT7	24.98	21.80	27.40	7.33	6.91	7.86	305.50	236.00	361.00	69.19	9.00	367.00	612.63	479.00	722.00	1.62	0.00	3.98	49.09	6.24	200.00
MT10	25.36	23.30	27.40	7.09	6.59	9.35	129.69	102.00	166.00	24.19	6.00	49.00	260.63	208.00	335.00	3.68	1.20	7.39	30.31	5.18	156.20
MT13	22.97	21.50	25.10	7.15	6.35	7.62	199.81	163.00	478.00	24.13	3.00	128.00	405.38	328.00	961.00	3.23	0.30	6.42	46.66	5.60	224.00
DT16	24.71	22.90	27.20	6.86	6.12	9.36	263.56	156.00	405.00	115.31	18.00	289.00	526.06	319.00	807.00	1.86	0.00	4.31	155.87	12.46	672.00
MD8	27.27	22.90	40.20	7.53	7.01	9.64	352.47	281.00	529.00	141.67	16.00	740.00	704.00	570.00	1024.00	1.71	0.00	4.40	124.94	16.10	856.80
MD11	24.76	21.50	27.80	6.97	6.45	7.62	513.38	224.00	935.00	404.50	14.00	2150.00	1037.81	449.00	1884.00	2.71	1.22	3.99	255.12	16.25	1806.00
MD12	24.71	23.00	26.00	7.43	6.99	8.08	512.19	220.00	1200.00	1243.19	214.00	3725.00	955.31	488.00	1316.00	0.98	0.00	2.45	1337.51	137.20	3192.00
MD14	25.27	23.00	27.50	7.61	7.15	8.31	600.50	199.00	747.00	237.44	105.00	395.00	1198.56	397.00	1500.00	1.47	0.00	3.82	251.60	5.60	1304.80
CT1	25.04	20.00	31.60	7.07	6.61	7.84	83.90	35.00	575.00	79.31	15.00	555.00	104.34	80.40	125.10	4.09	0.60	5.48	41.91	8.40	298.10
CT2	24.93	20.30	32.00	7.00	6.55	7.72	51.83	40.00	60.80	97.97	12.00	877.50	103.11	80.10	122.20	4.21	3.13	5.39	16.69	2.24	38.08
CT3	25.06	19.30	35.90	6.88	6.51	7.51	53.19	12.80	69.60	105.87	12.00	370.00	106.23	25.70	140.20	3.66	0.40	5.24	31.97	5.60	197.10
*WHO	40							2000					1000			5.0			50.0		
**NEMA	20-35				6-8			1200			100					5.0			50.0		

*WHO, (2008) maximum permissible limit of wastewater into aquatic habitat

**National Environmental Management Authority, (2006/2007) maximum permissible limit of wastewater into aquatic habitat; CT1, CT2 and CT3 are sites along Watindo Stream

factory discharge outlet, Kisekka market and Kibira Road Stream which is a surrogate discharge outlet for Uganda batteries Limited factory and Nice House of plastics factory (Table 3). Heavy metal concentration in rain for Pb (13 µm/L and 33 µm/L) was above water quality criterion value set for domestic supplies at WHO standards whereas, the rest were below the maximum permissible limits. The levels of concentrations of lead in rain water were far below that in stream water. Elemental concentrations of Pb, Cd, Cu and Zn were below the concentrations in effluents observed by Nabulo *et al*., (2008) except Cd at Peacock paint factory effluent which was in the same order of magnitude. However heavy metal concentrations in stream water along the Nakivubo Channel were in the same order of magnitude with those observed by Muwanga and Balifaijo, (2006).

Manganese concentrations exceeded the limit of 1000 µm/L as the maximum permissible limit of wastewater discharge into the environment at Mukwano industries, Peacock paint factory outfall and Kayunga tributary inflows leading to its accumulation downstream. The concentration of heavy metals along Watindo Stream ranged from 50 ± 18 to 106 ± 47 µm/L Pb; 2 ± 1 to 5 ± 2 µm/L Cd; 5 ± 2 to 14 ± 6 µm/L Cu; 20 ± 4 to 241 ± 5 µm/L Zn; 155 ± 145 to 165 ± 135µm/L Mn and 4050 ± 250 to 4600 ± 1000 µm/L Fe (Table 3). The mean Cd concentration in stream water at site CT01 and CT02 exceeded WHO (2008) maximum permissible limit for drinking water. But Pb, Cu, Mn and Fe concentrations in water of several magnitudes higher than surface water standards (Table 3). This phenomenon is of common occurrence in most populated urban areas close to industrial establishments (Mohiuddin *et al*., 2010).

Analysis of variance: The two-way ANOVA in table 4a-b indicate that sites show no significant effect on variation between groups of means of the heavy metals at deferent stream sections (Table 4a). However, the mean heavy metal concentrations of elements within

Table 3: Mean values and SE of trace metal concentrations in water at different sites along Nakivubo Channelized Stream and its Tributaries, Industrial effluent, rain water and Watindo Stream (n=16)

	Heavy metals (µg/L)					
Sites	Pb	Cd	Cu	Zn	Mn	Fe
Nakivubo stream						
US01	44±18	4±2	9±30	26±6	600±500	300±300
US02	45±20	4±2	12±6.0	26±5	535±465	500±100
US03	129±70	9±4	44±35	34±7	505±495	300±200
US04	3±9.0	3±1	8±2.0	46±7	685±215	900±400
MS05	53±26	5±2	27±20	59±9	955±145	1250±350
MS09	63±24	4±2	21±12	37±6	1000±300	1200±100
DS15	81±23	6±4	15±6	51±8	675±125	1050±350
DS17	88±24	4±2	13±6	33±5	1035±650	1450±550
Tributaries						
MT07	64±20	4±2	6±2	31±5	1915±185	2000±700
MTS10	63±24	3±2	16±7	49±14	155±145	250±250
MT13	75±30	3±6	18±12	32±6	475±425	1000±200
DT16	106±27	4±2	9±3	157±34	475±25	1250±450
Industrial Effluents						
MD08	100±34	4±2	25±0.008	65±18	1415±1384	900±800
MDS11	69±25	12±5	8±0.003	51±11	2400±700	800±700
MD12	113±31	6±2	18±0.004	144±24	670±30	3050±550
MD14	93±37	3±2	15±0.003	92±15	165±35	600±100
Watindo stream						
CT01	106±47	4±2	14±0.006	20±4	160±140	4050±250
CT02	75±31	5±2	5±5	24±5	155±145	4300±400
CT03	50±18	2±1	11±6	22±4	165±135	4600±100
Rain water						
Rw1n	13±9	2±1	14±7	18±5	50±50	200±200
Rw2w	33±19	3±1	25±20	21±3	10±10	100±0
**WHO, 2008	10	3	2000	3000	100	300
* NEMA, 2006	100	100	1000	5000	1000	
***surface water	0.015	-	1.3	-	0.05	0.3

* National Environment Management Authority maximum permissible limit of wastewater into aquatic habitat; ** World Health Organisation maximum permissible limit of drinking water; ***For surface water; Rw1n: rainwater collected in experimental site (Nakivubo); Rw2w: rainwater collected in control site (Namalere research centre-Watindo)

sites differed significantly at different stream sections; upstream ($F_{3,15}$ =27.33, P < 0.001); midstream ($F_{1,5}$ =1828.280, P < 0.001) and downstream ($F_{1,5}$=51.620, P < 0.001), at P = 0.05.Sections of the stream have significant effect on the mean heavy metal concentrations ($F_{2,30}$ = 13.3, P < 0.001), Table 4b. However, there was also a significant difference among heavy metal concentrations between sections of the stream ($F_{2,30}$ = 139.26, P < 0.001). The effects of interaction between sections and mean heavy metal concentration was significant ($F_{2,30}$ = 5.79, P < 0.001) suggesting a transport phenomenon or mobility of heavy metals.

Correlation analysis: Pearson correlation coefficients for the data were evaluated to determine the level of inter-metal association and the values are shown in Table 5. Elemental pairs Pb/Cd (r = 0.56); Pb/Zn (r = 0.50); Cd/Mn (r = 0.52) and Mn/Fe (r = 0.56) were significantly correlated with each other, suggesting that each paired elements have identical source or chemical phenomena, whereas the rest of the elemental pairs are not correlated with each other. The association of Mn with Fe in stream water may strengthen terrigenous sources and/or geo-chemistry. Metals show correlation with the physico-chemical characteristics. Pairs Pb/TDS, Pb/EC, Cd/EC, Zn/EC, Zn/BOD and Mn/EC are positively correlated with each other and Zn/DO and Fe/DO were negatively correlated, suggesting their Physico-chemical associations, whereas the rest of the metals and physico-chemical parameters are not correlated. Positive correlation of Cd/EC elemental pair was consistent with that of Kar *et al.*, (2008). Table 5 also shows that pairs BOD/TDS, BOD/TSS, DO/EC, TDS/DO, EC/TDS and TSS/TDS were significantly correlated with each other, whereas the rest of the pairs are not correlated. Very high BOD and very low DO in the stream water suggest pollution by organic matter and decomposition as a self purification mechanism. This phenomenon results into a reducing condition in organic rich stream water. These results are in line with those done by Igbinosa and Okoh, (2009). The development of reducing condition in stream water promotes the reduction of iron and manganese hydroxides (Linnik and Zubenko, 2000). Under slightly acidic to alkaline condition, Cd specifically adsorbed proportion is high in solid phase and Pb may occur bonded to poorly crystalline oxides (Fergusson 1990). The pH values (slightly acidic to alkaline), may limit the degree of desorption of heavy metals into solution and can promote co-precipitation except Pb at pH > 6 the solubility is governed by soluble organic ligands under reducing conditions (Muwanga, 1997). Contaminants released to flow in restricted water bodies at the mixing event can promote co-precipitation (Anazawa *et al.*, 2004).

Cluster analysis and factor analysis: Cluster analysis was performed on the data using Average linkage and correlation coefficient distance. Results of cluster analysis are shown in Fig. 3. Four groups of elemental associations with eigenvalue > 1 were

Table 4a: Two-way ANOVA results for sites and heavy metal concentration variables (Dependant variables were log-normal transformed)

Stream sections	Source of Variation	DF	SS	MS	F	P
Upstream	Sites	3	0.003	0.001	0.920	0.454
	Metal content	5	0.162	0.032	27.330	0.000
Midstream	Sites	1	0.000	0.000	0.180	0.689
	Metal content	5	0.255	0.051	1828.280	0.000
Downstream	Sites	1	0.002	0.002	2.210	0.197
	Metal content	5	0.238	0.048	51.620	0.000

DF-degree of freedom; F-factor mean square SS- Sum of squares; MS- Mean square; P = 0.05

Table 4b: Two-way ANOVA results for stream sections and mean heavy metal concentration variables (dependant variables were log-normal transformed)

Source of Variation	DF	SS	MS	F	P
Sections	2	0.000	0.01232	13.3	0.000
Metal content	5	1.000	0.12904	139.26	0.000
Sections*Metal	10	0.000	0.00536	5.79	0.000

SS- Sum of squares; MS- Mean square; P = 0.05

extracted in the analysis. Heavy metal elements were fused into clusters because of their relative elemental concentrations at each site and their similarity coefficients. Group I contains Pb and Cu while group II consists of Cd, Mn and Fe. Group III contains Zn as well as BOD, TDS, EC, TSS and stream water pH.

Biplot of sites and elemental concentrations suggest that Kibira Road stream is a source of Zn, Pb and copper, whereas Mukwano industries is a point source of Zn and Pb (Fig. 3). Sadoline paint factory was the point source of Pb and Zn, whereas NWSC is the point source of Cu, Zn and Pb. Inflows of Kayunga Stream into the Nakivubo Channelized Stream comes with Mn and Cd. The lengths of the arrow for Pb and Zn suggest that NWSC were the highest source, Peacock paint factory for Fe, Kayunga and Lugogo streams for Mn and Cd.

The firs factor accounts for 35.7 % of the total variance and contains Zn and Fe as well as water pH, total dissolved solids, TSS, electrical conductivity and BOD, with high variable loadings on this factor (Table 6) and corresponds to group III of the cluster analysis. Organic factor may indicate point sources such as municipal and industrial effluents and adsorption by TDS as well as flocculation or co-precipitation which is pH controlled (Balachandran *et al.*, 2005; Karbassi *et al.*, 2007; Abdel-Ghani and Elchaghaby, 2007; Abdel-Ghani *et al.*, 2009) TDS and TSS seems to play a major role in the adsorption of heavy metals in stream water rich with organic matter. These phenomena remove heavy metals rapidly and render it free of contamination under varying dissolved salts.

The second factor accounts for 19.9 % of the variance and contains Cd, Mn and Fe with high variable loadings on this factor which corresponds to group II of the cluster analysis. This indicates co-precipitation of Cd with Mn and Fe oxides/ hydroxides. The third factor accounts for 16.8 % of the variance and contains Pb, Cd and Cu with high variable loadings on this factor and corresponds to group I of the cluster analysis. This factor is considered to represent anthropogenic toxic pollutants from metal works and fabrications, vehicular and industrial emissions. Distribution of Zn between different factors 1 and 2 may suggest dual sources whereas pH indicates its influence as a controlling factor on heavy metal co-precipitation.

Table 5: Pearson correlation coefficient matrix (r) for mean heavy metal contents and physicochemical characteristics in Nakivubo Channelized Stream water (n=16)

	Pb	Cd	Cu	Zn	Mn	Fe	Temp	pHw	TDS	TSS	EC	DO	BOD
Pb	1												
Cd	0.56*	1											
Cu	0.30	0.12	1										
Zn	0.50*	0.14	-0.01	1									
Mn	0.23	0.52*	-0.09	-0.18									
Fe	0.27	0.33	-0.19	0.38	0.56*	1							
Temp	-0.35	-0.29	-0.07	-0.01	-0.11	-0.34	1						
pHw	0.25	-0.18	0.25	0.36	-0.20	0.00	0.11	1					
TDS	0.49*	0.32	-0.17	0.47	0.31	0.48*	-0.20	0.42	1				
TSS	-0.13	-0.02	-0.28	0.13	-0.05	0.14	0.21	0.17	0.56*	1			
EC	0.67**	0.48*	-0.14	0.55*	0.49*	0.43	-0.14	0.30	0.83**	0.18	1		
DO	-0.54	-0.22	0.03	-0.53*	-0.44	-0.56*	0.26	-0.42	-0.77**	-0.25	-0.83**	1	
BOD	-0.07	-0.14	-0.14	0.53*	-0.24	0.44	-0.10	0.31	0.48*	0.65**	0.13	-0.32	1
pHs	0.12	0.36	0.12	0.03	0.35	0.15	0.49*	-0.03	-0.21	-0.004	0.03	0.02	-0.20

* Correlation is significant at the 0.05 level (2-tailed), ** Correlation is significant at the 0.01 level (2-tailed) pHw; water pH, pHs; sediment pH

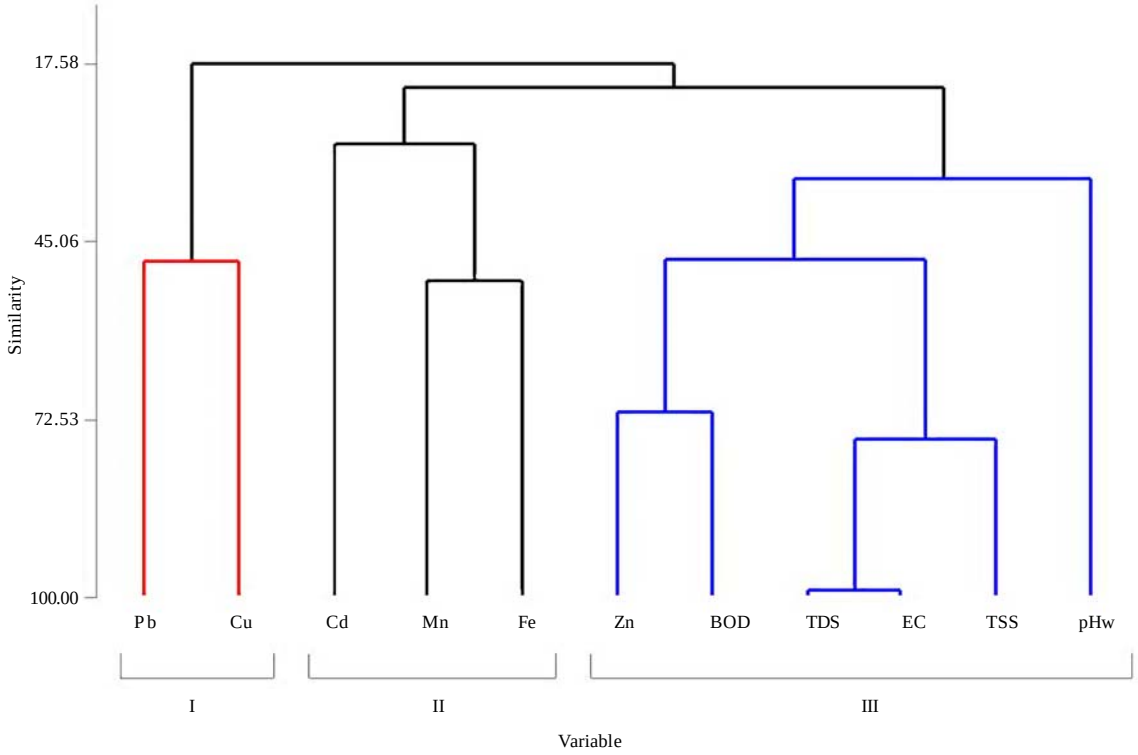

Fig. 3: Dendrogram of elemental concentrations and physico-chemical parameters of Nakivubo Channelized stream water and industrial discharge effluents (n=16)

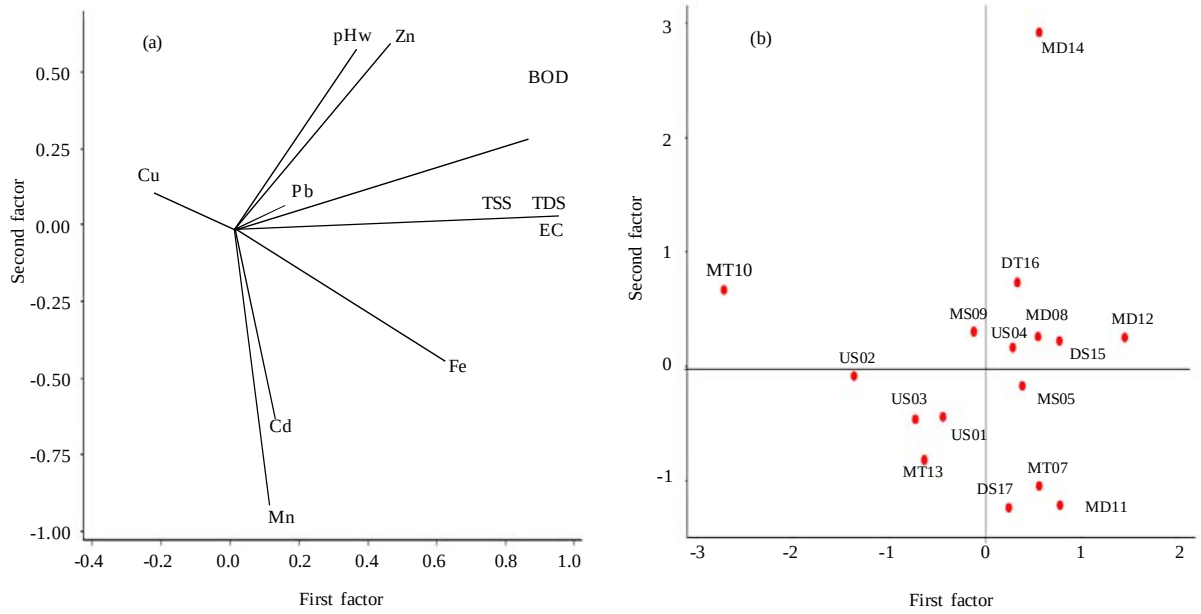

Fig. 4: Biplot of elemental concentrations (a) and sites (b) of stream water

Table 6: Rotated factor loadings and communalities of elements and physico-chemical characteristics in stream water samples (n=16)

Variable	Factor 1	Factor 2	Factor 3	Communality
Pb	0.152	0.075	0.865	0.777
Cd	0.121	-0.613	0.525	0.666
Cu	-0.237	0.122	0.791	0.697
Zn	0.451	0.608	0.211	0.618
Mn	0.102	-0.896	-0.044	0.815
Fe	0.614	-0.428	0.077	0.567
pH-w	0.352	0.589	0.266	0.542
TDS	0.924	0.041	0.068	0.859
TSS	0.799	0.036	-0.231	0.693
EC	0.944	0.041	0.27	0.909
BOD	0.858	0.294	-0.045	0.824
Variance	3.9269	2.1912	1.8494	7.9675
% Var.	0.357	0.199	0.168	0.724

CONCLUSION

The Nakivubo Stream water is stripped of heavy metal contaminants. Because of this, the quality of the Nakivubo aquatic ecosystem is improved. However, high anoxic conditions attributed to biochemical processes and decomposition of organic matter as a purification mechanism (organic matter pollution) poses a threat to aquatic life. The greatest threat in Nakivubo Channelized Stream water would be posed by Pb and Cd which almost always occur as mobile elements in water under neutral to alkaline conditions but are always rapidly removed. Flocculation and co-precipitation of Mn and Fe hydroxides, water pH and TDS could be the major mechanism explaining the rapid removal of Pb and Cd to bottom sediments. The levels of dissolved oxygen were below the maximum permissible limit, while the mean biological oxygen demand was above the maximum permissible limit. FA results reveal two sources of pollutants as explained by three factors (72.40 %); (i) mixed origin or chemical phenomena of industrial and vehicular emissions, and (ii) dual origin of Zn (vehicular, commercial establishment and industrial). Atmospheric deposition of heavy metals especially Pb in rain is apparent and may be attributed to vehicular emissions.

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