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Research Article

Distribution of Metals along Simiyu Wetland of Lake Victoria Basin and its Impact on Agriculture

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Abstract

More than 70% of communities living along Simiyu wetland area are agriculturalists and pastoralists. Physical land degradation and poor nutrient mobility within the soil-plant system have shown a notable impact on agricultural production. Cycling of selected and their impact on agriculture were investigated along Simiyu wetland. Cation Exchange Capacity (CEC) of the soil was studied with respect to soluble cations and selected trace metals. To study the longitudinal and spatial distribution of the selected metals along Simiyu wetland, samples (water, sediments and soil) were taken in three stations along the river namely Bariadi Bridge, Simiyu Bridge and the Simiyu River mouth. Sampling of soil was done at different distances from the river so as to study the flow pattern of the metals and hence to explain the direction of cycling. Sampling was done both inn wet and dry seasons to study the seasonal variation of the metals. Geographical Position System was used to locate the sampling points for soil and water/sediment. Metals Chromium (Cr), Lead (Pb), Zinc (Zn), Coper (Cu), Cadmium (Cd) and Manganese (Mn) analyses were analyzed by atomic absorption spectrophotometer (AAS). High levels of Manganese and Zinc were detected in most samples with different distribution behavior between water and sediments that may reflect difference in solubility of metals in water or possible complex formation of the metals resulting to potentially less solubility of metals, hence retarding their bioavailability to plants low cation exchange capacity. Retarded nutrient mobility in clay soils was observed facilitated by the formation of hard pans resulting to less availability of the nutrients to plants. The study suggests some ways in which farmers can improve soil cation exchange capacity and hence improve agricultural productivity.

Key words: *Trace elements, soluble cations, cation exchange capacity, wetland*.

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INTRODUCTION

Management of ecosystem functions is an important aspect of sustainable use of natural resources. Sustainable management requires the maintenance of biodiversity and of other vital ecosystem functions and processes such as cycling of nutrients and water. Resource management also needs social mechanisms that receive, interpret and process feedback signals from the ecosystems in adaptive ways. Lake Victoria is an important natural resource for Kenya, Uganda and Tanzania. The lake is currently undergoing degradation because of human activities that are threatening the Lake Victoria environment and the surrounding wetland areas. Wetlands are potential source of natural resources for the community surrounding Lake Victoria (Namakambo 2000; Swallow et al 2001) High population increase and rapid industrialization accompanied with untreated waste disposal are contributing to the degradation of the wetlands and the quality of Lake Victoria environment.

The routes at which pollutants are carried down into the wetlands vary from those emanating from point sources to those from non-point sources. Human activities including agriculture facilitates loading of pollutants by adding pollutants to point sources like in the fields for pesticides and nutrients. The pollutants are partly filtered by the soils, sediments and the plants but some of the pollutants eventually enter the lake (Makundi 2001). Among the pollutants that are threatening the wetland environment of Lake Victoria are trace elements (Nabulo et al 2008; Henry and Omutange 2009; Mutakyahwa et al 2009). Trace elements are toxic to living organisms including human being when present at higher concentration than required for normal growth; they can be accumulated through food chain system. Trace elements in contaminated soil, sediments and water can be taken up by plants, fish and reach human being through food chain (Chang et al 1995; Birley and Lock 1999).

Nutrients availability in soil, water and sediments can as well be affected by heavy metals pollutants. Other variable that affect nutrient availability in the soil are soluble cations such as magnesium, potassium, calcium and magnesium. Soil characteristics and management conditions affecting nutrient availability are very important for the prediction of nutrient behaviour in the soil-plant system. It is based on these factors that the mobility of the nutrients between the soil profiles can be related to the receiving of the nutrients by the associated wetlands. Further, fractionation of the nutrients in sediments/water column depends on the solubility of the metals and their complexation behaviour (Mwamburi and Oloo 1997).

The present study assessed the levels in different points of the wetlands, the flow pattern of the same and also the contribution of non-point sources/those carried along the atmosphere and finally deposited in depression areas by gravitation. This should be a key to the establishment of a rough pattern of cycling of the trace elements and organic pollutants of interest. In the current study the distribution of total metal at different locations along and across the river Simiyu was studied to assess the major source of the metals by observing their trend of distribution. The study was extended to study the soil characteristics and their relation to nutrient mobility for plant outreach. Furthermore, the common exploitation of the soil and sediment for agricultural use was assessed and hence the better ways of soil management for higher production suggested.

MATERIALS AND METHODS

Study area

This study was done along Simiyu River located in the Lake Victoria wetlands in Tanzanian part (Figure 1). The basin comprises a total catchments area of approximately 194,200 km and is located between latitudes $0^{o}20'$N $3^{o}0'$S and longitudes $31^{o}39'$E, $34^{o}53'$E and is shared by Kenya, Uganda and Tanzania.

Sample collection

Sampling was done in February 2008 before the heavy rains (dry season) while another sampling was done after the rains in August 2008 (wet season). Sampling was done in mainly three stations from upstream to downstream, with up to six sites for each station. In Simiyu wetland, the stations in sequence were Bariadi Bridge, Simiyu Bridge (along Mara road) and the Simiyu River mouth (Fig.1). At each station water and sediment samples were collected and 3 samples of soil at different distances away from the river at the three stations to study the spatial variation of the residues. Locations of the sampling sites were done by GPS.

Water samples

Sampling of water was achieved by using water sampler. The samples were kept in 300ml glass bottles preserved at low pH prior to analysis. Samples were collected at least 5cm below the surface.

Sediment samples

About 25g samples of sediments were collected by using grab sampler and kept in glass bottles. The top sediment containing the organic matter was removed before packing the sediment for analysis.

Soil samples

Aliquots of 30 g Soil samples were obtained by coring at a depth in between 5-10 cm deep and wrapped in aluminium foil prior to analysis. Soil samples for soluble catioins analysis were collected from more sites as shown on Fig 7 including the common three sites for other samples.

Identification and Quantification

Standard methods were used in the total metal analysis as described by Burton and John (1977), ie. Digestion of soil and sediments by using a triple acid system of fuming nitric acid (4 ml) hydrofluoric acid (2 ml) and perchloric acid. For the analysis of sediment samples, a method outlined by Agemian and Chau (1975) was followed where nitric acid (concentrated), perchloric acid and hydrofluoric acid were used for digestion. Water samples and digested samples of both soil and sediments were analysed in Atomic Absorption Spectroscopy (AAS).

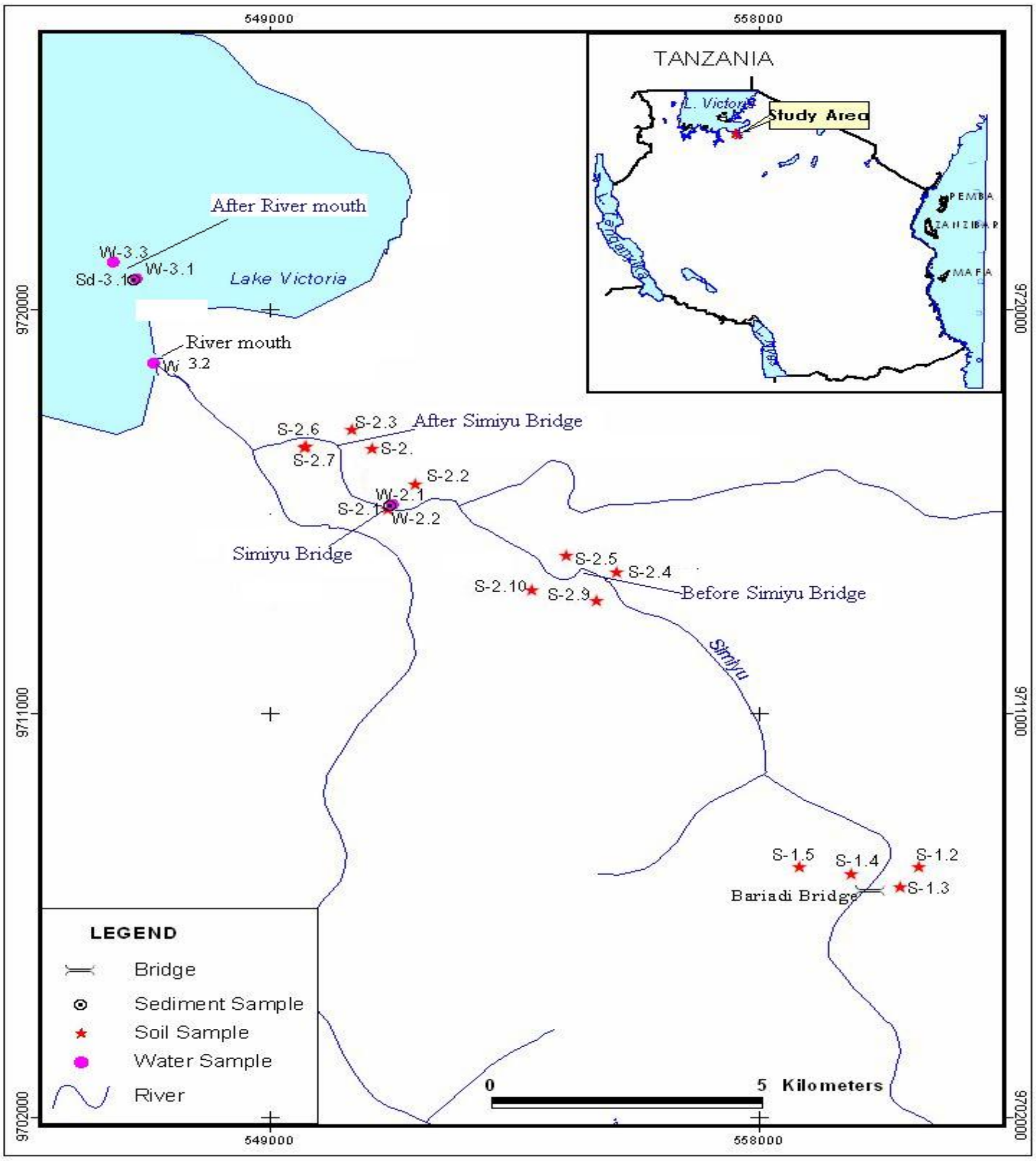

Figure 1. Sampling sites along Simiyu wetlands

RESULTS AND DISCUSSION

Distribution of Cr, Pb, Zn, Cu and Mn in water

Water samples were analyzed for Cr, Pb, Zn, Cu and Mn residues. The results showed generally the highest mean concentrations of residues of up to 0.8 µg/L, 3.4 µg/L, 1.0 µg/L, 0.8 µg/L and 0.8 µg/L in Simiyu wetland for Cr, Pb, Zn, Cu and Mn, respectively (Figure 2). Generally, of these maximum levels were recorded during the wet season in all stations except Simiyu River mouth. The general trend of detection is Pb> Zn>>>Cr/Cu/Mn with relatively higher levels of Pb recorded at stations 1 (Bariadi Bridge), 2 (Before Simiyu Bridge) and 3 (at Simiyu Bridge). After Simiyu station had higher levels of Zn during dry season, all other metals had higher levels during wet season. The study of the metal distribution along the Simiyu wetland from upstream to downstream did not show any definite trend indicating an absence of a point source as could be related to the human activities along and across the land. The levels in Simiyu were generally low with Cd not detected in all the samples. The maximum levels of metals in water at Simiyu were recorded during the wet season most probably due to inputs from different sources through flooding. The study of longitudinal variation of metals was done to assess the trends, of the elements downstream to the wetland and hence to the lake. Relatively high levels of lead in wet season near the river mouth that could be attributed by lead from traffic washed away by rainy water down to the lake. This is supported with the presence of high levels of Pb in water in before the Simiyu Bridge and in Simiyu Bridge (Figure 2). The wetland is surrounded by a number of fields ranging from horticultural to other crops like cotton and maize. Hypothetically, the application of nutrients in the fields could be noted in the trend and hence the fields acting as point sources. Seasonal and longitudinal variations could indicate the amount transported through down to the wetland. However, the results indicated insignificant variations between seasons and among stations indicating no possibility of the fields acting as point sources. When compared to other previous related studies, the levels reported here are within the concentrations reported from other areas (Table 1) in Lake Victoria basin (Kisamo 2003; Kishe and Machiwa 2003; Nabulo et al 2008; Mutakyahwa et al 2009).

Distribution of Cr, Pb, Zn, Cu and Mn in sediments

Sediment analyses indicated relatively higher levels of Mn in all stations ranging between (127-310) µg/g dry mass and (118-300) µg/g dry mass in dry and wet seasons, respectively (Figure 3). No Cd was detected in all samples. Zn was relatively high in both water and sediments while Pb, Cu and Cr were recorded at very low levels in the sediments some of them recorded below detection limits (Figure 2 & 3). The highest concentrations of Zn were detected at Before Simiyu Bridge and Simiyu Bridge stations (Figure 3). The general trend of metals recorded in sediments was Mn>Zn>>>>>others. Availability of metals in sediments depends on a number of factors such as their solubility in water, their source and their nature. In both seasons Mn has shown an outstanding abundance in most fractions. Detectable levels of Cd were found in the sediments, they were generally below the detection limits (non-detectable levels). Generally, the dry season recorded slightly higher levels of Mn and Zn in Bariadi Bridge and Simiyu than the wet season that may be due to dilution. Other metals except Pb After Simiyu River Station had their highest mean concentrations during wet season. The highest metal concentrations during wet/rainy season could be attributed by contamination from other sources through rainy and flooding. Primarily, sources of heavy metals in sediments can be due to ore deposits, particularly those that are being actively mined, and industrial activities (Larsen 2000; Ek and Renberg 2001). Mn showed relatively constant concentrations in both water and sediments indicating no longitudinal trend that may suggest existence of underlying rock uniformly distributed along the wetland. No Cd was detected in all samples. Zn was relatively high in both water and sediments while Pb, Cu and Cr were recorded at very low levels some of them recorded below method detection limits (Figure 2 & 3). The general trend of metals recorded in sediments was Mn>Zn>>>>>others. Compared to studies, the reported concentrations of sediments in this study are within values that have been reported in other areas in Lake Victoria basin (Kisamo 2003; Kishe and Machiwa 2003; Nabulo et al 2008; Mutakyahwa et al 2009).

Distribution of Cr, Pb, Zn, Cu and Mn in soils

Soil analysis was done to assess for any point source in the nearby fields surrounding the wetlands. In the study, Mn and Zn were relatively higher compared to other metals (about 1000 times higher), with levels up to 800 and 200 µg/g dry mass, respectively, both recorded during the dry season (Figure 4). These levels were comparatively higher than those found in sediments (up to 300 µg/g dry mass and 100 µg/g dry mass, respectively). Generally, higher concentrations of all metals analysed were detected during wet seasons. The levels of Cr, Pb and Cu were very low with Cd concentration below detection limits. Soil characteristics and management conditions affecting nutrients availability are very important for the prediction of nutrients behaviour in the soil-plant system. It is based on these factors that the mobility of the nutrients between the soil profiles can be related to receiving of the nutrients by the associated wetlands. Further fractionation of the nutrients in sediments/water column depends on the solubility of the metals and their complexation behaviour. Soil an analysis was done to assess for any point source in the nearby fields surrounding the wetlands. In the study, Mn and Zn were relatively high compared to other metals, with levels up to 800 and 200 µg/g dry mass, respectively, both recorded during the dry season Figure 4). These levels were comparatively higher than those found in sediments (up to 300 µg/g dry mass and 100 µg/g dry mass, respectively). Compared to other studies (Kisamo 2003; Nabulo et al 2008) concentrations of

Pb Cu, Cr and Cd in this study are relatively lower, while concentration of Zn is within the values reported by other studies in Lake Victoria basin (Table 1). Generally, the mean highest concentrations of heavy metals were detected during wet season; this could be associated with input of heavy metals from various sources through flooding during rainy season. According to previous studies possible sources of heavy metals are; soil erosion, mining and other industrial activities, agricultural practices, and waste disposal from large villages and urban areas (Dalkıran et al 2006). Comparison of the obtained data for soil and water with data obtained for same metals from other parts of the Lake Victoria basin is shown on Tables 1 and 2.

Soil characteristics and the leaching capacity of the nutrients

Extraction of the samples by 0.4 HCl and 1.0 M NH_4 CH_3 COO consecutively, indicated that the higher fraction of the soils around Simiyu are contained in the residual fraction Pb (100%), Cd (24%), Cu (18%), Zn (26%) and Mn (31%), respectively (Henry and Omutange 2009). In sediments the residual fractions contained Pb (36%), Cd (27%), Cu (18%), Zn (26%) and Mn (51%), respectively. However, a good portion could not be allocated in either residual or non residual fractions indicating the fraction that could not be extracted by the two solvents. This shows the degree of leaching capacity of the metals reflecting higher capacity through the soils and sediments. Soil management is essential to allow metals to move along the soils and sediments. Formation of hardpans affects this mobility of the nutrients as they move along with the draining water. When the hard pans forms they limit the water movements and hence the nutrient mobility. Mn & Zn are essential elements and Mn plays a key role in photosynthesis process. Though required in small amounts their safety levels are influenced by a number of factors, nutrient bioavailability- soil properties (particulate matter in soil coloids, texture, structure), plant properties (uptake capacity), the entire nutrient (solubility, density, form it exist etc) and environmental factors (pH, temperature, salinity).Analysis of soil characteristics along Simiyu showed that the soil and sediments are mostly characterized by clay particles with pH ranging from 7.5 to 7.7 and % carbon ranging between 2 to 6 (Henry and Omutange 2009).

The study from different sites along simiyu indicates the trend Ca^{2+} > Na^{+} >K^{+} >Mg^{2+} as shown in the figure 7 for stations 1-7 corresponding to Maligisu, Ididi, Bugandando, Lumeji, Bridge, River mouth and river mouth + 100 m along the river

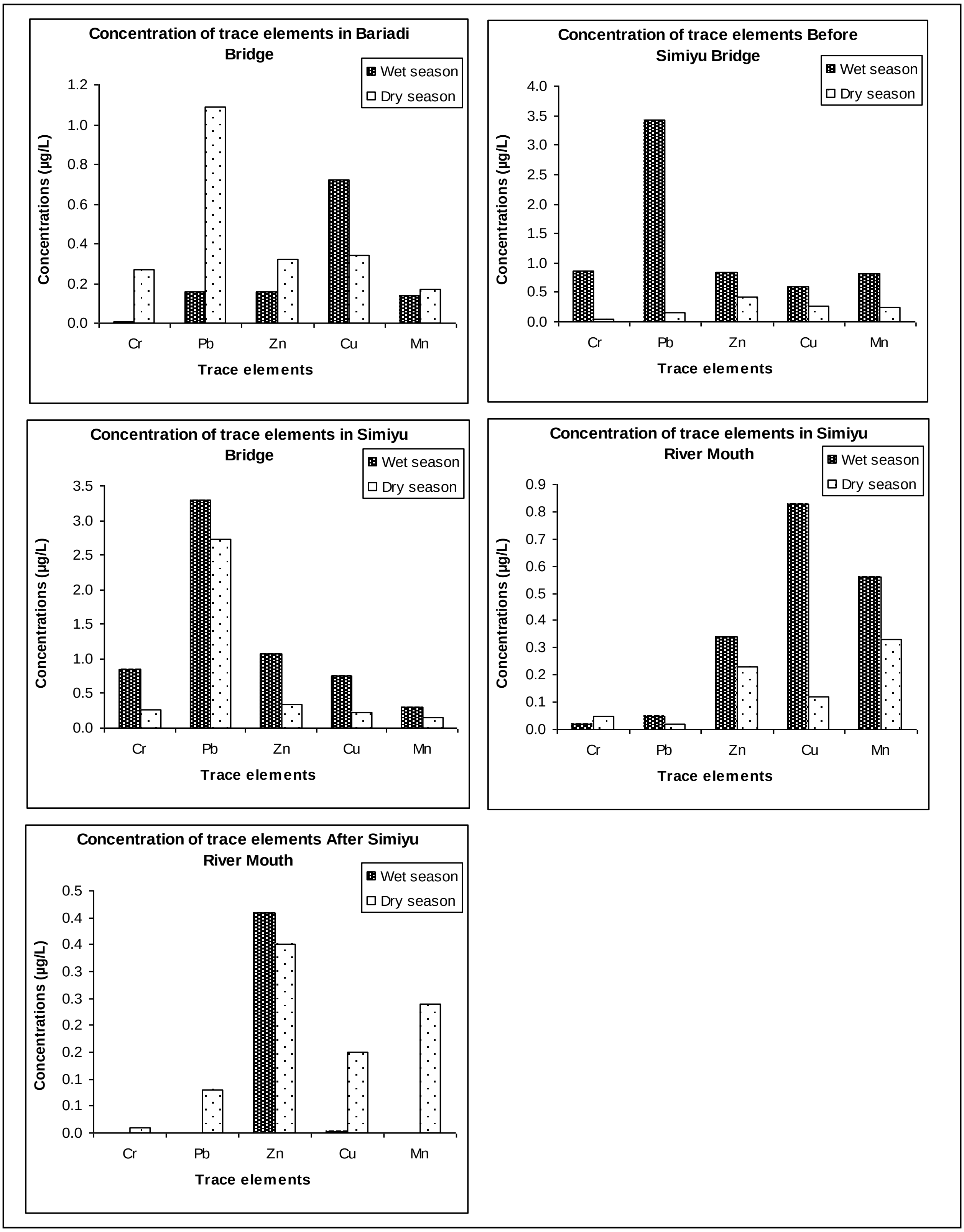

Figure 2. Trace elements variation during dry and rainy season in water collected from Simiyu wetland area.

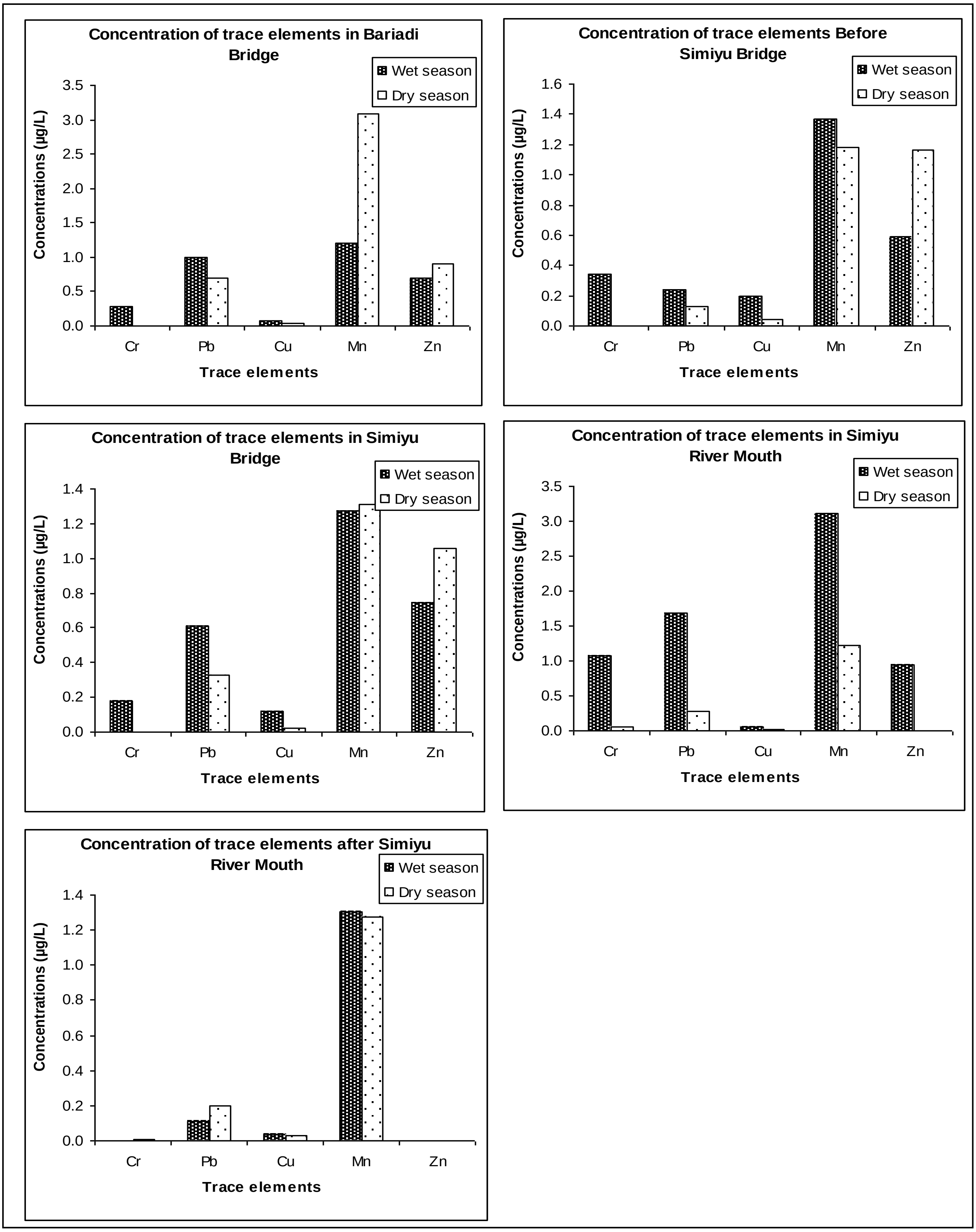

Figure 3. Trace elements variation during dry and rainy season in sediments collected from Simiyu wetland area. Note that, values for Mn and Zn shown in the figure are 100 times less.

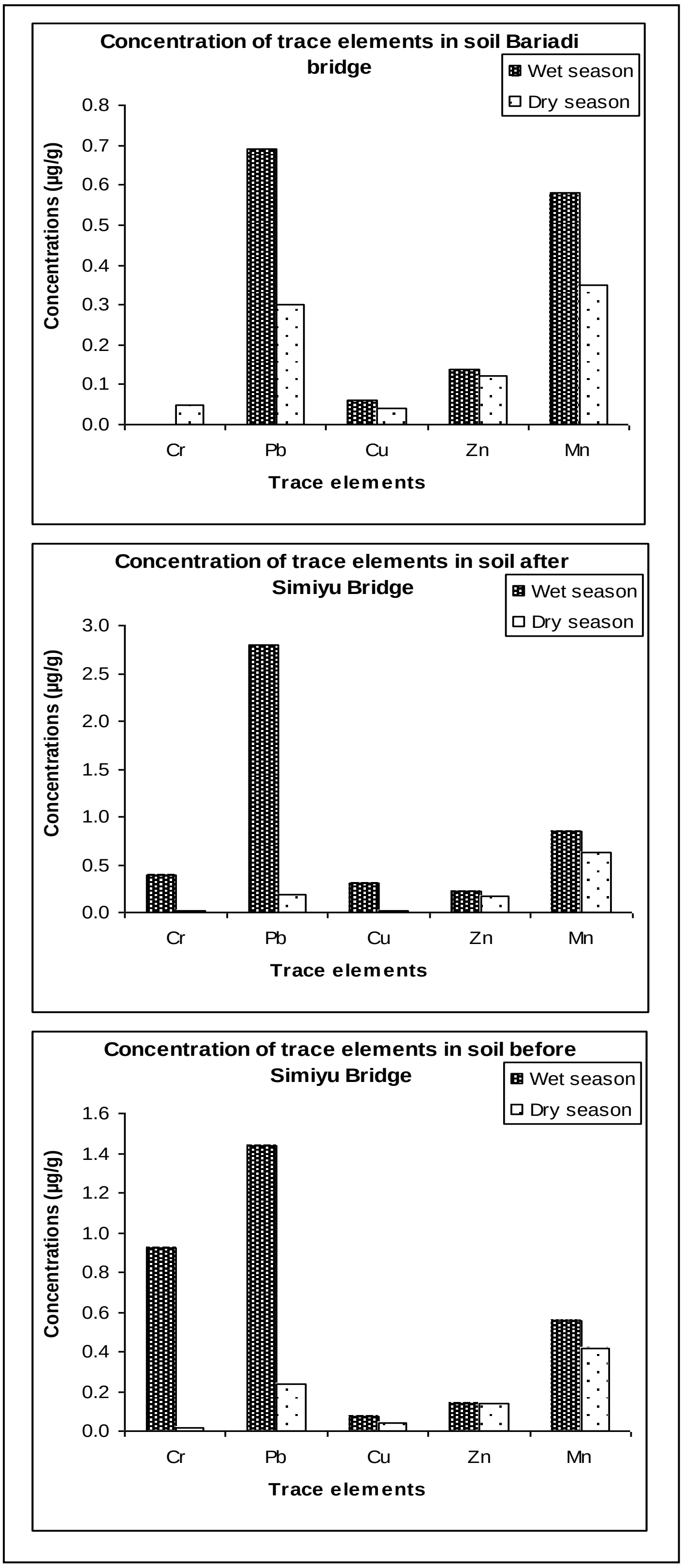

Figure 4. Trace elements variation during dry and rainy season in soil collected from Simiyu wetland area. Note that, values shown in the figures for Cr and Zn are 1000 times less.

Table 1 Reported levels of trace elements in soil (in mg/kg dry mass) from different area of Lake Victoria wetlands

Site	Pb	Cr	Cd	Zn	Cu	Mn
Kirumba[a]	4.8	1.6	0.253	20.0	1.7	-
Ilemela[a]	9.2	3.2	0.16	9.0	2.9	-
Mirongo[a]	65.6	10.2	0.46	137.0	21.4	-
Magu[a]	36.4	27.5	0.52	78.0	25.7	-
Simiyu[a]	38.8	31.2	0.551	80.0	26.1	-
Bariadi bridge[b]	0.5	0.025	ND	129.2	0.02	463.5
Before Simiyu bridge[b]	0.84	0.49	ND	138.4	0.05	481.5
Simiyu bridge[b]	1.45	0.2	ND	192.2	0.16	735.5
Katonga[c]	171.5	-	-	387.5	1.20	-
Bukasa[c]	105.5	-	-	318.4	51.13	-
Namuwongo[c]	98.2	-	-	260.3	42.13	-
Bwaise[c]	67.3	-	-	237.7	34.50	-
Murchison Bay[c]	54.1	-	-	230.3	28.70	-
Kitawataka[c]	49.2	-	-	225.6	42.47	-
Kyebando[c]	30.1	-	-	67.9	12.03	-
Munyonyo[c]	27.2	-	-	53.3	19.77	-
Banda[c]	27.2	-	-	58.8	14.00	-
Busoga[c]	18.0	-	-	40.4	10.33	-
Butabiga[c]	15.3	-	-	30.7	12.77	-
Ewers(1991)[d]	100	-	-	100	-	-
ICRCL (1997)[e]	50	-	-	25	10	-
Ewers (1991)[f]	50	-	-	200	50	-

a- Kisamo (2003).
b- Current study, Henry and Mamboya (2012).
c- Nabulo et al (2008).
d- Recommended guidelines value for maximum limit of heavy metals in irrigation soils.
e- Mean of heavy metal limits in soil used for agriculture and recreation recommended by interdepartmental committee for redevelopment of contaminated land (ICRCL).
f- Guideline values for tolerable total metal concentration in agricultural soil recommended by the Swiss Ordinance.

Table 2 Levels of trace elements in water in mg/L dry mass

Site	Pb	Cr	Cd	Zn	Cu	Mn
Kirumba[a]	0.35	<0.01	0.01	0.08	<0.01	-
Ilemela[a]	0.45	<0.01	0.01	0.06	<0.01	-
Mirongo[a]	0.63	<0.01	0.01	0.04	<0.01	-
Magu[a]	0.42	<0.01	0.01	0.04	<0.01	-
Simiyu[a]	0.40	<0.01	0.01	0.04	<0.01	-
Bariadi bridge[b]	0.08	0.1	ND	0.24	0.5	0.15
Before Simiyu bridge[b]	0.46	1.55	ND	0.63	0.45	0.50
Simiyu bridge[b]	3.0	0.55	ND	0.7	0.49	0.23
Simiyu river mouth[b]	0.035	0.035	ND	0.29	0.48	0.48
After Simiyu River mouth[b]	0.005	0.04	ND	0.175	0.075	0.12
Simiyu[b]	3.4	0.8	-	1.0	0.8	0.8
Katonga[c]	0.25	-	-	0.56	0.08	-
Bukasa[c]	0.05	-	-	0.02	ND	-
Namuwongo[c]	0.05	-	-	0.16	0.02	-
Bwaise[c]	0.05	-	-	0.22	0.025	-
Murchison Bay[c]	0.05	-	-	0.05	ND	-
Kitawataka[c]	ND	-	-	0.16	0.04	-
Kyebando[c]	0.15	-	-	0.90	0.005	-
Munyonyo[c]	ND	-	-	0.02	0.005	-
Banda[c]	0.05	-	-	0.25	0.01	-
Busoga[c]	0.05	-	-	0.28	0.005	-
Butabiga[c]	0.01	-	-	0.11	0.02	-
USEPA(2001)[g]	0.065	-	-	2.0	0.017	-

a -
Kisamo, D.S. 2003
b- Current study, Henry and Mamboya 2012
c- Nabulo et al 2008
d- Recommended guidelines value for maximum limit of heavy metals in irrigation soils
e- Mean of heavy metal limits in soil used for agriculture and recreation recommended by interdepartmental committee for redevelopment of contaminated land (ICRCL)
f -Guideline values for tolerable total metal concentration in agricultural soil recommended by the Swiss Ordinance

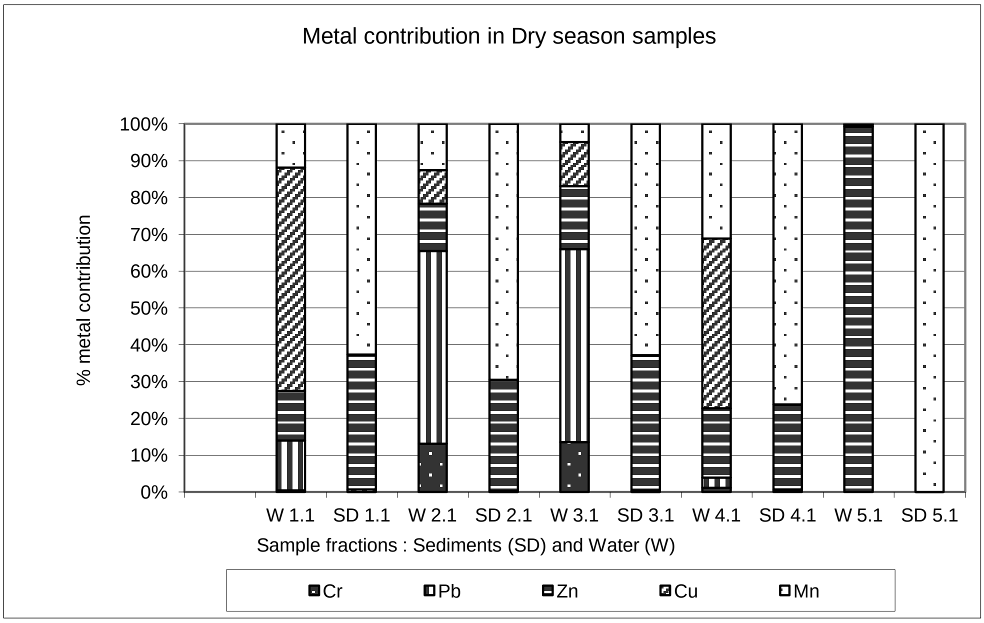

Figure 5: Distribution of metals in the sample fractions of water and sediments (in µg/L and µg/g dry mass, respectively) in Dry season at Simiyu (1.1 =Station 1dry season; 1.2 = Station 1 rainy season, W= water; SD= Sediments; S= Soil.)

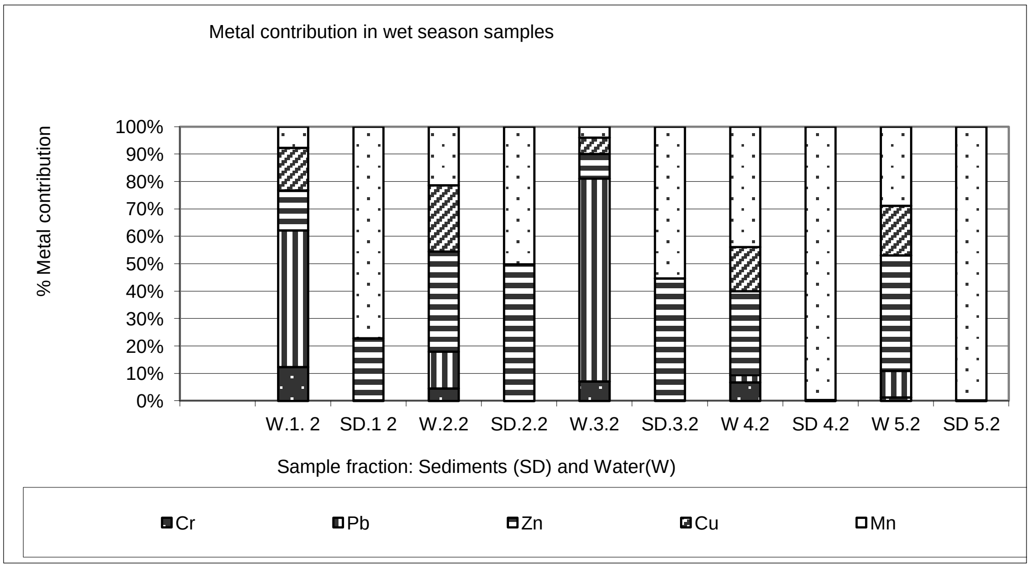

Figure 6: Distribution of metals in the sample fractions of water and sediments (in µg/L and µg/g dry mass, respectively) in Wet season at Simiyu (1.1 =Station 1dry season; 1.2 = Station 1 rainy season, W= water; SD= Sediments; S= Soi l.)

Simiyu. The farmers showed habits of applying manure and mulching to their farms during preparations that supports efforts of improving the CEC of the soil along the River Simiyu. The practice enhances retention capacity of nutrients for easy plant up take.

Wetland utilization with regard to availability of trace metals

The study shows that the trend from upstream to down stream for the metal distribution is lacking with insignificant variations between dry and wet season. The wetland is highly utilized for agricultural activities. The study indicates high contribution of parent rock (Nyazarian-Kanroindo rock) to the availability of metals rather than the contribution from human inputs. However, the availability of metals is compounded with the common activities related to agriculture. Activities like land cultivation, deforestation cause land degradation, water stream flowing out of the rocks and mining activities contributing to the continuous exposure of the underlying rock.

Soil Modification for nutrient outreach by plants

Based on the type and structure of soils along Simiyu, formation of hard pans has been a big challenge in the movement of nutrients and other minerals for plant use. Mn, Zn and Cu were generally dominant in soil and sediment samples. The study analyzed for presence of soluble cations that would influence the cation exchange capacity (CEC) of the soil in relation to the impact on agriculture. The CEC is the one that improves the quality of the soil for higher productivity that results to the bioavailability of essential nutrients to plants uptake.

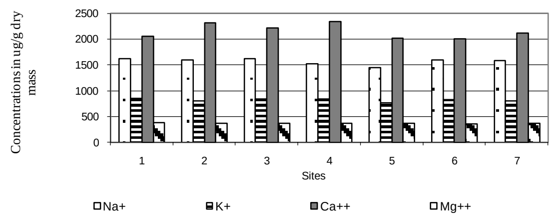

Figure 7: Levels of soluble cations in soil along Simiyu wetland

The study from different sites along simiyu indicates the trend Ca^{2+} > Na^{+} >K^{+} >Mg^{2+} as shown in the above figure for stations 1-7 corresponding to Maligisu, Ididi, Bugandando, Lumeji, Bridge, River mouth and river mouth + 100 m along the river Simiyu. The farmers showed habits of applying manure and mulching to their farms during preparations that supports efforts of improving the CEC of the soil along the River Simiyu. The practice enhances retention capacity of nutrients for easy plant up take.

CONCLUSION AND RECOMMENDATIONS

The wetland utilization for agricultural activities is highly influenced by the natural make up of the land and human activities in the wetlands. The CEC of the soil is the results of balanced mobility of nutrients within the soil – plants environment. In clay soils the formation of hardpans affect nutrients exchange between the surface soil, underlying soil and the plants, resulting to poor distribution of the nutrients and poor uptake by plants as well. However, the presence of soluble cations in the plant environment influences the CEC of the soil and hence good uptake. The above explanations call for good agricultural practices for soil modification to facilitate the nutrient mobility in the soil. The study therefore suggests increased carbon contents through mulching of the farms (land covers) and manure application to improve the CEC and hence the nutrient availability to plants. Based on the leachability studies the high leaching capacity was observed indicating the possibility of high loss away from was the plants could reach.

The availability of the heavy metal elements in levels above the background in the wetlands, south of Lake Victoria is attributed mainly to gold mining activities. Copper, Pb and Zn showed a tendency of positive correlation in the areas which are experiencing both large and small scale mining activities.

Where as the parent rock contributes to availability of the contribution from human activities through artificial fertilizers, traffic, garages and burial sites as noted along the wetlands cannot be undermined. Pollutants emanating from these sources have significant movements from one component of the wetland to others. The study of the soil/sediment characteristics showed high clay contents of the wetland soil/sediment that reduces the leachability of the pollutants. The study of seasonal variation shows no significant differences between dry and wet seasons. No trend was observed along and across the wetlands for both dry and wet seasons. The study of the seasonal variations of metals along and across the wetland has the following conclusive findings;

Generally distributions of the metals in Simiyu were within acceptable limits (not alarming). The spatial and longitudinal variations as well as seasonal variations of the residues along the wetland indicated absence of a specific trend suggesting a point source / erosion of parent rock rather than human activities. The catchments utilization related to the metals cycling across and along the wetlands by contributing to continued exposure of underlying rocks through land tillage, deforestation, mining activities and water streams running out of the rock were cited.

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