IMPACT OF AGRONOMIC INPUTS IN SUGARCANE FARMING ON TOTAL HEAVY METAL LEVELS IN AQUATIC ECOSYSTEMS AND SOILS WITHIN LAKE VICTORIA BASIN, KENYA.

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Abstract.

Sugarcane farming has been identified as the single most cultivated cash crop in Lake Victoria basin. Use of high agronomic inputs is employed in these regions for better yields. Most rivers feeding Lake Victoria from these catchments have been reported to accumulate total heavy metals downstream above background concentrations. The source of these heavy metals to the rivers is not known. This study, therefore, aimed at determining levels of pH, Cd, Cu, Zn, Pb and Cr in River Kuywa surface water and sediments before and after traversing sugarcane farms within Lake Victoria basin as well as in farm soils, canals runoff water and sediments within the sugarcane farms to assess if agronomic input in sugarcane farming influenced their levels. The results indicated significant differences at $p \leq 0.05$ in the heavy metal levels of River Kuywa before the farms and after the farms. Canals water and sediments levels were significantly higher than river water levels suggesting them to be the main contaminants to the river. In addition canals values differed significantly from the control canal implicating agronomic inputs over the increase. However, soil levels did not differ significantly from their control with all the values going beyond international standards suggesting the area to have higher background concentrations of these metals. None the less, soil pH and total organic carbon values differed significantly between the sugarcane farms and the control implicating agronomic inputs in sugarcane farming over their increase that aided in mobility of the naturally occurring metals to the aquatic systems.

Key words: Lake Victoria catchment; sugarcane farming; River Kuywa; heavy metals; agronomic inputs; Kenya.

Introduction

River Kuywa originates from Mount Elgon before traversing several sugarcane farms in Bungoma County in Western Kenya and finally joins River Nzoia to drain into Lake Victoria. Sugarcane was found to be the single most important cash crop extensively grown in this region by small scale farmers, large scale farmers and company/factory nucleus estates (Netondo *et al*., 2010). Most small scale farmers rent out their land to companies/factories hence adopting high agronomic inputs such as the ones used in the nucleus estates (Netondo *et al*., 2010; GoK, 2002).

Intensive agronomic inputs such as nitrogenous fertilizers, pesticides and sewage sludge are employed in these zones for high yields (Allen, 2009). The impact of these agronomic inputs in sugarcane farming on river water quality is of major concern since animals and humans use this water domestically apart from the general aquatic life sustainability of the rivers and their sinks.

Assessment of heavy metals at the mouths of major rivers feeding Lake Victoria on the Kenyan side (Rivers: Nzoia, Sio, Nyando, Kuja, Awach and Yala) reveal levels of total Cd, Pb, Cu, Cr and Zn in both aerobic sediments and water beyond background concentrations (Lalah *et al*., 2008, Ongeri, 2010). These authors suggest that the elevated levels are due to agricultural activities taking place in the Lake Victoria catchments. This research aimed at justifying this claim by determining the levels of heavy metals (Cd, Cu, Zn, Pb and Cr) in River Kuywa water and sediments before and after traversing sugarcane farms and in soils, runoff water and sediments in canals draining water from the sugarcane farms to the river. This was done both in the long wet and dry seasons with the results being compared to controls selected such that agronomic inputs in sugarcane farming was the only major difference.

In other areas like Australia, especially in the Great Barrier Reef, aquatic systems in sugarcane farms have been found to contain heavy metals beyond background concentrations (Haynes, 2001); indicating that the activity has a positive effect on heavy metal concentration. However, of major concern in most of the research in sugarcane field is the lowering of soil pH by inorganic fertilizers (Wood, 2003; Oliver, 2004). A change in soil pH is usually accompanied with other chemical changes in sugarcane fields like converting both naturally occurring and arthropogenically added heavy metals to bioavailabe and mobile forms hence raising the possibility of aquatic contamination due to surface runoffs, leaching and soil erosions (Oliver, 2004; Alloway, 1995).

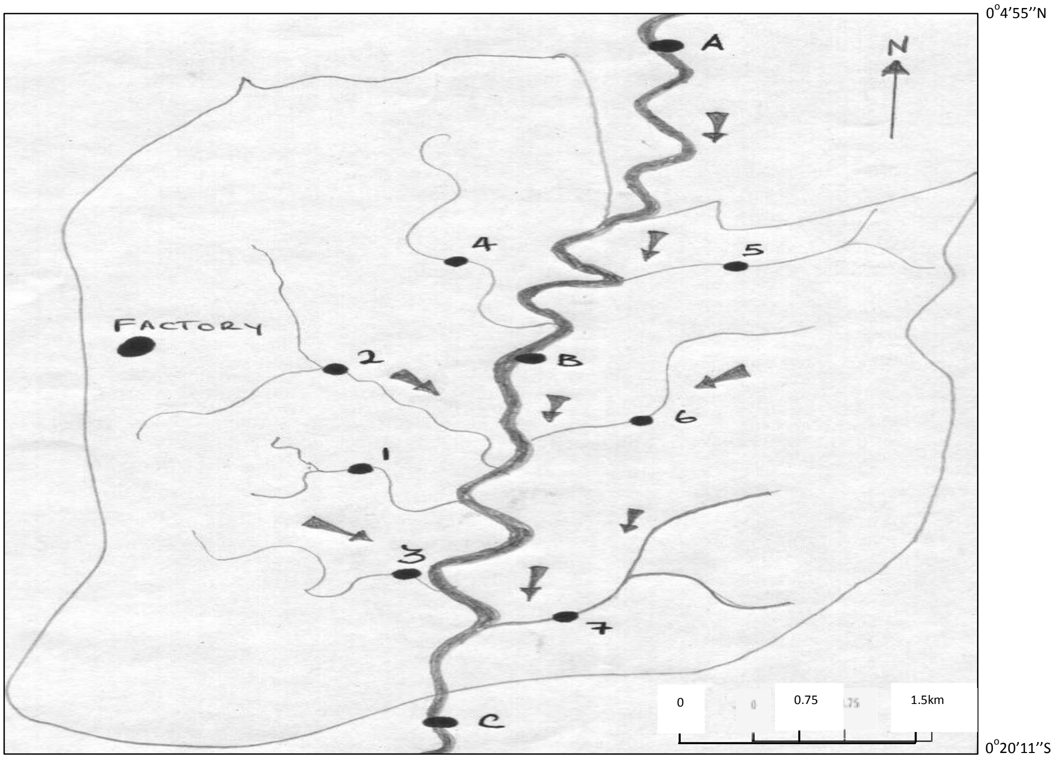
Materials and Methods

The study was carried out in sugarcane farms traversed by River Kuywa between 34^{o} 50$^{'}$ 49$^{''}$ E to 35^{o} 35$^{'}$ 41$^{''}$E longitudes and 0^{o} 4$^{'}$ 55$^{''}$N to 0^{o} 20$^{'}$11$^{''}$S latitudes. The farms are located in Bungoma County within Lake Victoria catchment region that is one of the main sugarcane producing areas in Western Kenya. The studied sugarcane farms have many water canals which run across the farms and discharge waste water into River Kuywa that flows through the farms before joining River Nzoia that finally drains into Lake Victoria.

Experimental design and sampling

A site on River Kuywa before entering the sugarcane farms was used as a control for the river. Two other sites on the river, within the middle of the farms and at the end of the farms, were used to get the total impact of sugarcane farming on River Kuywa aquatic ecosystem. Different specific canals were chosen with respect to farming activities taking place in the locations where the canals drained water into and sampling sites located at strategic points along the canals as illustrated in Figure 1. Site 1 was located on a canal that drained water from a tree plantation that had no agronomic inputs and was at a higher elevation with no possibility of receiving water flow and/or leachate from other areas hence used as a control to check agronomic inputs impact. Site 2 was located on a canal draining water from the factory premises. Site 3 was located on a canal draining water from freshly cultivated plots. Site 4 was located on a canal draining water from sugarcane farms awaiting harvesting and sites 5, 6 and 7 were located on canals that drained water from sugarcane fields that were approximately 1, 2, and 5 months old during the dry season and 3, 5 and 7 months old during the wet season respectively. Soil samples from the farms where the canals drained water from were also sampled at random. Soil samples from a football pitch in a nearby school that was at an elevated level with no possibility of receiving heavy metal leachate and or erosions from sugarcane farms was used as a control for the soils of sugarcane farms. Most of the cane fields in site 3 had sugarcane planted during the wet season sampling whereby Di Ammonium Phosphate (DAP) fertilizer was used at the rate of 3.4 bags of the 50 kg bags per hectare while most of the plots in site 5, 6 and 7 had Urea fertilizer and pesticides application during the wet and dry seasons respectively.

Sampling was done during the dry season in February 2009 and wet season in May 2009. Water pH and turbidity were measured directly in the field using a pH meter (3071 Jenway) and a turbidity meter (HI 93703) respectively. Four replicates of 500 ml surface water samples were taken from each sampling site in glass bottles using a grab sampler, transported in an ice box to the laboratory and refrigerated at 4°C according to John *et al.* (1996) prior to analysis. Ten replicates each measuring 100 g of surface soil (2 cm deep in cross section sampling of 5m apart) and four replicates of surface sediments (2 cm deep) were sampled per site using a hollow plastic pipe, kept in black plastic bags and transported in an ice box to the laboratory for processing. The sediments and soils were air dried at room temperature; ground by a pestle and motor then sieved through a 45 µm mesh sieve and kept in clean plastic containers ready for analysis.



34° 50' 49'' E
35° 35' 41''E

Key: River Kuywa: /; Canals: /; 1 – 7: Sampling sites on canals; A – C: Sampling points on River Kuywa.

Sampling sites grid positions: **1** – 0° 33' 53.25''N, 34° 39' 37.27''E. elev. 1475 m. **2** – 0° 34' 15.67''N, 34° 39' 36.57''E. elev. 1470 m. **3** – 0° 32' 17.07''N, 34° 40' 40.43''E. elev. 1432 m. **4**

– 0° 31’ 54.11’’N, 34° 40’ 15.71’’E. elev. 1420 m. **5** – 0° 35’ 03.20’’N, 34° 41.12’’E. elev. 1438 m. **6** – 0° 32’ 56.16’’N, 34° 41’ 18.72’’E. elev. 1428 m. **7** – 0° 32’ 31.39’’N, 34° 41’ 12.45’’E. elev. 1428 m. **A** - 0° 36’ 11.37’’N, 34° 41’ 20.20’’E. elev. 1438 m. **B** - 0° 34’ 24.22’’N, 34° 40’ 49.07’’E. elev. 1431 m. **C** - 0° 31’ 32.80’’N, 34° 40’ 43.86’’E. elev. 1417 m.
Fig. 1: The map of the sampled sugarcane farms from Lake Victoria basin in Western Kenya.

Sample analysis

For soil and sediments pH, a method adopted from Rhodes (1982) was used; whereby 50 ml of deionized water was added to 20 g of crushed soil/sediment, stirred well for ten minutes and allowed to stand for 30 minutes before stirring again for two minutes followed with pH measurement using a pH meter (3071 Jenway).

Total organic carbon for both soils and sediments was determined by measuring 10 g of a well mixed air dried sample and heating it in an oven for 3 hours at 105°C in a crucible to remove water vapor then placed in a Vulcan A-550 muffle furnace and temperature raised gradually from 105°C to 550°C for eight hours. The difference in weight between the resultant ash and the moisture free sample was noted as the total organic carbon (Okalebo, 2002). The Hydrometer method was used to measure % silt of both the soil and sediment samples (ASTM 152H with scale in g/l) (Zhu *et al.,* 2004).

Heavy metals in water samples were determined by filtering 200 ml of the sample through a 1 µm cellulose acetate filter with mill pores into an acid-washed 500 ml Erlenmeyer flask. The sample was then acidified to about 1% by adding 2 ml of concentrated nitric acid (analytical grade), placed on a hot plate at 60°C and allowed to evaporate to approximately 30 ml (Mzimela *et al*., 2003). The evaporated sample was then transferred to a 50 ml volumetric flask and made up to volume with double distilled water after addition of 1.5 mg/ml of strontium chloride (Ikuo *et al*., 1965). The extract was analyzed for Cd, Cu, Zn, Pb and Cr using a calibrated (with specific salts) Shimadzu AA-6200 Atomic Absorption Spectrophotometer with specifications outlined in Table 1

Heavy metals in surface sediments and soils were determined by taking ten grams of air dried surface sediments/soils and moisture content determined by drying in an oven at 105°C, cooled in a desiccator and weight measured. The difference in weight was noted then the sample was put in a 50 ml Pyrex digestion tube and 10 ml mixture of concentrated nitric acid and concentrated hydrochloric acid (4:1, aqua ragia digestion) added. This was followed by a digestion of 3 hours in a Gerhardt digester at 100°C, the contents were filtered through 0.45 µm polyethersulfoon filter membrane into a 50 ml volumetric flask and made up to volume with double-distilled water (Tack and Verloo, 1999) after addition of 1.5 mg/ml of strontium chloride (analytical grade, $SrCl_2.6H_2O$, Ikuo *et al*., 1965).The extracts were analyzed for Cd, Cu, Zn, Pb and Zn using the conditions of the AAS discussed above.

Method detection limits for all the analytical methods were determined using respective standards (Table 1) in accordance to method 40 CFR 136 and recovery studies done by spiking acid washed sediments/soils, double distilled water for water samples, with twenty times the method detection limits concentration of standards in accordance to method 40 CFR 136 (USEPA, 2007).

Analysis of variance (ANOVA) at $P \leq 0.05$, a factorial two experiment and least significant differences at $P \leq 0.05$ were used to check the variations. Statistical analysis was performed using MSTATC two factor completely randomized design, with season as the main factor and site as the sub treatment.

Results and discussion

Detection limits for the various methods used in this research have been recorded in Table 2 while the AAS machine operation specifications are recorded in Table 1. Zinc lamp did not pass line search at the given lamp current of 8 mA but after trial and error 6 mA worked. The results have been recorded in Tables 3, 4, 5, 6 and 7 for river and canal water, river and canal sediments and soil samples respectively. Average wet weight to dry weight ratios for sediment samples was 1.035 ± 0.024 for river and 1.054 ± 0.011 for canals while for cane farm soils and control farm soils it was 1.027 ± 0.014 and 1.001 ± 0.002 respectively.

Table 1: Atomic Absorption flame emission Spectrophotometer (Shimadzu AA-6200) experimental specifications

Element	Cd	Cu	Cr	Zn	Pb (II)
Lamp current	8	6	10	6*	10
Wavelength (nm)	228.8	324.7	357.9	213.9	283.3
Slit width (nm)	0.7	0.7	0.7	0.7	0.7
Mode	BGC-D_2	BGC-D_2	BGC-D_2	BGC-D_2	BGC-D_2
Flame	Air-C_2H_2	Air-C_2H_2	Air-C_2H_2	Air-C_2H_2	Air-C_2H_2
Fuel flow (l/min)	1.8	1.8	2.0	2.0	2.0
Prespraytime	3 sec	3 sec	3 sec	3 sec	3 sec
Integration time t	5 sec	5 sec	5 sec	5 sec	5 sec
Calibrations	0.1-0.6	0.1-0.6	0.1-0.6	0.1-0.6	0.1-0.6
MDL (ppm)	0.012	0.04	0.12	0.11	0.28

Key: MDL – machine detection limit; BGC-D_2 – Deuterium background correction (compensates for matrix interferences); * - the one recommended for the machine could not work hence tried

Table 2: Detection limits and recovery studies for various methods used in analysing heavy metals in samples from sugarcane farms traversed by R. Kuywa using AAS 6200 Shimadzu.

		Cd	Cu	Zn	Pb	Cr
Water samples	Machine detection limits	0.012	0.04	0.11	0.28	0.12
	Method detection limits	0.08	0.14	0.09	0.11	0.07
	Recovery studies as a %	89	92	88	90	79
Sediment samples	Machine detection limits	0.012	0.04	0.11	0.28	0.12
	Method detection limits	0.12	0.07	0.11	0.17	0.15
	Recovery studies as a %	88	89	93	87	88
Soil samples	Machine detection limits	0.012	0.04	0.11	0.28	0.12
	Method detection limits	0.13	0.11	0.21	0.11	0.22
	Recovery studies as a %	77	76	87	89	80

Table 3: Mean seasonal variations of heavy metals in River Kuywa water traversing sugarcane farms within Lake Victoria catchments.

		pH	Cd μg/l	Cu μg/l	Zn μg/l	Pb μmg/l	Cr μg/l
Dry	R. Kuywa before sugarcane farms	7.30	0.66	1.87	17.20	1.62	0.35

season	R. Kuywa in the middle of sugarcane farms	7.20	0.81	2.40	26.31	1.84	0.21
	R. Kuywa after the sugarcane farms	7.00	0.97	2.53	28.13	1.89	0.50
	Dry season mean	**7.17**	**0.81**	**2.27**	**23.88**	**1.78**	**0.35**
Wet season	R. Kuywa before sugarcane farms	6.27	0.92	4.41	41.85	4.70	0.68
	R. Kuywa in the middle of sugarcane farms	6.16	1.08	6.41	65.49	3.56	0.82
Statistics	R. Kuywa after the sugarcane farms	6.00	1.54	8.90	66.18	5.44	0.95
	Wet season mean	**6.14**	**1.19**	**6.57**	**57.81**	**4.57**	**0.82**
	LSD site dry season $p \leq 0.05$	0.23	0.07	0.54	4.35	0.24	0.06
	LSD site wet season $p \leq 0.05$	0.14	0.10	1.23	10.23	0.45	0.10
	LSD season mean $P \leq 0.05$	1.03	0.60	0.44	3.55	0.36	0.05
	CV%	3.54	5.17	16.56	5.74	27.51	6.22
Stds	Kenyan domestic water stds[a]	6.5-8.5	5.00	100.00	5000.00	50.00	NG
	Kenyan Aquatic life stds[a]	5-9.0	≤1.1	NG	NG	3.21	NG
	US EPA domestic water stds[b]	5-9.00	5.00	1000.00	7400.00	50.00	NG
	US EPA aquatic water stds chronic[b]	6.5-9.0	0.25	NG	120.00	2.50	16.00
Other studies	Canadian aquatic life Stds[c]	NG	0.017	2-4.00	30.00	1-7.00	1-9.00
Key:	R. Nzoia mean at the mouth of L. Victoria[d]	6.75	ND	30.00	89.1	29.50	ND
	R. Yala mean at the mouth of L. Victoria[d]	6.70	ND	10.10	26.0	42.00	ND
	R. Yamun, India[e]	NG	62.7	72.90	66.7	71.7	ND

LSD – Least Significant Difference; CV%: percent coefficient of variation in replicated sample; NG – not given in literature; ND – not detected; stds – standards; a – EMCA, 2006; b – US EPA, 2009; c – Francis, 2008, d – Lalah *et al.,* 2008; e – Jain, 2004.

Table 4: Mean seasonal variations of heavy metals in canals runoff water within sugarcane farms traversed by River Kuywa within Lake Victoria catchment.

		pH	Cd µg/l	Cu µg/l	Zn µg/l	Pb µg/l	Cr µg/l
Dry season	1. Canal from tree fields (control)	6.76	0.69	1.81	31.18	1.16	0.09
	2. Canal from the factory premises	6.61	0.91	2.60	63.19	3.82	0.42
	3. Canal from new cultivated plots	7.04	0.81	2.72	46.92	1.40	2.40
	4. Canal from mature cane fields	6.23	1.12	2.39	33.88	1.47	0.90
	5. Canal from 1 months cane fields	6.86	1.14	2.26	41.93	1.72	0.80
	6. Canal from 2 months cane fields	7.01	1.01	3.39	88.44	1.80	2.36
	7. Canal from 3 months cane fields	8.13	1.31	3.08	33.92	1.72	0,97
	Dry season mean	**6.95**	**1.00**	**2.61**	**48.49**	**1.87**	**1.33**
	1. Canal from tree fields (control)	6.20	0.80	6.07	40.56	4.72	0.60
	2. Canal from the factory premises	5.53	1.51	11.34	242.00	5.35	2.31
Wet season	3. Canal from newly planted plots	5.53	1.74	7.94	327.37	4.59	3.12
	4. Canal from mature cane fields	4.40	1.14	19.08	194.77	5.78	1.11
	5. Canal from 3 months cane fields	5.73	1.90	16.72	132.00	5.19	1.58
	6. Canal from 5 months cane fields	4.80	2.55	19.52	178.19	5.49	0.96
Statistics	7. Canal from 7 months cane fields	4.13	2.06	14.27	181.67	5.46	2.20
	Wet season mean	**5.19**	**1.67**	**13.56**	**185.22**	**5.22**	**1.69**
	LSD site dry season $p \leq 0.05$	0.26	0.09	0.72	23.75	0.42	0.25
	LSD site wet season $p \leq 0.05$	0.69	0.12	0.54	19.90	0.54	0.32
	LSD seasons mean $P \leq 0.05$	0.56	0.05	0.39	12.70	0.22	0.13
	CV%	3.11	1.34	6.56	4.25	8.55	12.93
	Kenyan domestic water stds[a]	6.5-8.5	5.00	100.00	5000.00	50.00	NG
Stds	Kenyan Aquatic life stds[a]	5-9.0	≤1.1	NG	NG	3.21	NG

	US EPA domestic water stds^{b}	5-9.00	5.00	1000.00	7400.00	50.00	NG
	US EPA aquatic water stds chronic^{b}	6.5-9.0	0.25	NG	120.00	2.50	16.00
	US EPA aquatic water stds acute^{b}	6.5-9.0	2.00	NG	120.00	65.00	16.00
	Canadian aquatic life stds^{c}	NG	0.017	2-4.00	30.00	1-7.00	1-9.00
Key	NB: Dry season sampling done in February and wet season sampling done in May 2009; LSD – Least Significant Difference; CV%: percent coefficient of variation in replicated sample; NG – not given in literature; stds – standards; a – EMCA, 2006; b – US EPA, 2009; c – Francis, 2008.						

In the dry season, river water pH differed significantly from the time the river entered the sugarcane farms to the time it left the farms (Table 3). The same situation was repeated in the wet season even though the wet season values were significantly lower than the dry season values (Table 3). As River Kuywa left the sugarcane farms, especially during the wet season, its pH values were below the expected levels in Kenyan domestic water standards (Table 3).

The reduction in River water pH values were explained with the lower values recorded in canals feeding this river from sugarcane farms (Table 4). These canals drained water from different cane fields with different activities. Canal 1 that was used as a control registered a significantly higher pH value than the rest (Table 4). Canal 2 that drained water from a factory premises did not differ significantly from the control canal suggesting that factory activities might not be affecting the pH values. This might look debatable until we mention the fact that the sewage from the factory was not considered nor the treatment plants for it was believed that the acidification problem from chemicals used in processing sugar were corrected in the lagoons. However, most of the areas canal 2 drained water from were from open fields and staff residential areas. This was aimed at assessing if maybe contaminants from the atmosphere around the factory and its workers could have an effect on pH and other values.

However, this research finds addition of agronomic inputs in sugarcane farming to have a detrimental impact on water pH. A case in mind is canal 3 that had just been freshly cultivated as virgin land and the water pH values from these farms were not different from the control canal during the dry season. A problem came in when the plots had been planted with young cane during the wet season using DAP and the difference in pH values were now significantly different from the control (Table 4).

Canal 4 posed a special case whereby the sugarcane fields that was ready for harvesting in both seasons registered significantly different values in the two seasons (Table 4). This situation can be explained by the fact that during the dry season, there is no transport media to transfer the contaminants from the plots to the canals as is the case in the wet season with plenty of surface runoffs and soil erosions. Sites 4, 5, 6 and 7 that had its plots applied with Urea fertilizer during the wet season registered lower pH values that differed from one canal to the other significantly (Table 4).

It is therefore evident from water pH data that agronomic inputs in sugarcane farming affect the pH of aquatic systems. The verdict is further justified with similar results being recorded in sediments of both river and canals although the sediments values are a notch higher due to bioaccumulation effect. Not only were the fertilizers the only agronomic inputs but also others like sewage sludge and pesticides applied during the wet and dry season respectively which may equally play a significant role in pH reduction as we shall see later. The average pH in River Nzoia downstream of 6.75 is reflective of the effects of sugarcane farming activities along its basins.

Table 5: Mean seasonal variations of heavy metals in River Kuywa surface sediments traversing sugarcane farms within Lake Victoria catchments (dry weight)

		pH	TOC %	Cd mg/kg	Cu mg/kg	Zn mg/kg	Pb mg/kg	Cr mg/kg
Dry season	R. Kuywa before sugarcane farms	6.70	5.65	3.53	35.27	104.23	28.22	29.19
	R. Kuywa in the middle of sugarcane farms	6.50	6.54	3.84	38.27	132.42	37.33	46.45
	R. Kuywa after the sugarcane farms	6.30	6.87	4.20	45.91	129.93	44.72	48.78
	Dry season mean	**6.50**	**6.35**	**3.86**	**39.82**	**122.19**	**36.77**	**41.47**
Wet season	R. Kuywa before sugarcane farms	6.05	6.64	3.98	65.62	122.86	65.91	50.34
	R. Kuywa in the middle of sugarcane farms	5.89	7.23	4.15	66.75	147.55	69.78	59.76
Statistics	R. Kuywa after the sugarcane farms	5.87	7.45	4.68	67.40	162.06	83.05	63.38
	Wet season mean	**5.94**	**7.10**	**4.27**	**66.59**	**144.16**	**72.92**	**57.83**
	LSD site dry season p ≤ 0.05	0.35	1.01	0.13	2.50	17.26	11.67	4.55
	LSD site wet season p ≤ 0.05	0.24	0.97	0.09	2.12	21.34	9.89	9.45
	LSD season mean P ≤ 0.05	1.21	1.23	0.11	5.30	14.09	9.53	5.67
	CV%	15.30	21.09	11.85	16.65	17.06	21.59	21.76
Stds	Canadian aquatic life stds ISQGs[b]	NG	NG	0.60	35.70	123.00	35.00	37.30
	Canadian aquatic life stds PELs[b]	NG	NG	3.50	197.00	315.00	91.30	90.00
	Ontorio aquatic life stds LEL[c]	NG	1.00	0.60	16.00	120.00	31.00	26.00
	Ontorio aquatic life stds SEL[c]	NG	10.0	10.0	110.00	820.	250.	110.

			0	0		00	00	00
	Australian aquatic life effect level[d]	NG	NG	1.50	32.00	117.00	39.00	207.00
Other studies	Lake Victoria[e]	NG	NG	7.97	80.7	93.8	94.6	NG
	R. Kisat at the mouths of L. Victoria[f]	7.20	NG	6.78	38.13	350.00	38.13	36.00
	R. Nzoia at the mouths of L. Victoria[f]	6.75	NG	8.00	87.53	198.00	102.32	75.23
	R.Kuja at the mouths of L. Victoria[f]	6.15	NG	2.08	50.09	168.00	50.09	50.34
	Great barier reef in Australia (sugarcane farms)[g].	NG	NG	0.50	32.00	117.00	39.00	207.00
Key	LSD – Least Significant Difference; CV%: percent coefficient of variation in replicated sample; NG – not given in literature; stds – standards; ISQGs - Interim Sediment Quality Guidelines; PELs - Probable Effect Levels; LEL - Lowest Effect Level; SEL - Severe Effect Level; a - EMCA, 2006; b - CCME, 2002; c - OMEE, 1993; d - ANZECC, 2000; e – Ongeri *et al*., 2010; f – Lalah *et al*., 2008; g - Haynes, 2000							

Table 6: Mean seasonal variations of heavy metals in canals surface sediments within sugarcane farms traversed by River Kuywa within Lake Victoria catchment (dry weight)

		pH	%TOC	Cd mg/kg	Cu mg/l	Zn µg/l	Pb µg/l	Cr µg/l
Dry season	1. Canal from tree fields (control)	**7.35**	**3.25**	**1.47**	**15.75**	**31.18**	**19.81**	**14.20**
	2. Canal from the factory premises	6.32	5.23	1.12	34.26	63.19	23.42	64.27
	3. Canal from new cultivated plots	6.50	4.87	1.87	31.69	46.92	25.44	51.63
	4. Canal from mature cane fields	6.15	6.43	1.84	25.04	33.88	29.04	51.80
	5. Canal from 1 months cane fields	7.76	7.98	2.15	31.67	41.93	30.95	59.53
	6. Canal from 2 months cane fields	6.88	5.87	2.55	18.12	88.44	33.67	48.61
	7. Canal from 3 months cane fields	6.57	6.76	2.11	24.70	33.92	26.20	14.66
	Dry season mean	**6.64**	**5.77**	**1.86**	**25.8**	**48.4**	**26.9**	**43.5**

					9	**9**	**3**	**3**
Wet season	1. Canal from tree fields (control)	**7.05**	**3.45**	**1.10**	**18.58**	**40.56**	**22.42**	**18.65**
	2. Canal from the factory premises	5.32	7.54	3.12	74.87	242.00	51.45	58.02
	3. Canal from new cultivated plots	5.42	6.87	3.60	81.78	327.37	54.16	94.52
	4. Canal from mature cane fields	3.69	7.98	2.22	56.41	197.77	50.79	74.53
	5. Canal from 3 months cane fields	5.55	10.45	4.39	45.46	132.00	56.46	52.82
	6. Canal from 4 months cane fields	5.00	6.95	3.24	20.26	178.19	51.14	106.30
	7. Canal from 7 months cane fields	4.05	7.67	2.16	55.58	181.67	51.13	86.10
	Wet season mean	**5.15**	**7.27**	**2.83**	**50.42**	**185.22**	**48.22**	**70.13**
Statistics	LSD site dry season p ≤ 0.05	0.36	1.45	0.08	5.96	23.75	4.06	5.97
	LSD site wet season p ≤ 0.05	0.43	1.98	0.10	6.87	26.98	7.06	6.98
	LSD seasons mean P ≤ 0.05	0.21	1.56	0.04	3.18	12.70	3.77	3.77
	CV%	14.56	13.54	26.65	21.43	23.75	19.09	17.18
Stds	Canadian aquatic life stds ISQGs[b]	NG	NG	0.60	35.70	123.00	35.00	37.30
	Canadian aquatic life stds PELs[b]	NG	NG	3.50	197.00	315.00	91.30	90.00
	Ontorio aquatic life stds LEL[c]	NG	1.00	0.60	16.00	120.00	31.00	26.00
	Ontorio aquatic life stds SEL[c]	NG	10.00	10.00	110.00	820.00	250.00	110.00
	Australian aquatic life effect level[d]	NG	NG	1.50	32.00	117.00	39.00	207.00
Key	NB: Dry season sampling done in February and wet season sampling done in May 2009; LSD – Least Significant Difference; CV% - percent coefficient of variation in replicated sample; NG – not given in literature; stds – standards; ISQGs - Interim Sediment Quality Guidelines; PELs - Probable Effect Levels; LEL - Lowest Effect Level; SEL - Severe Effect Level; a - EMCA, 2006; b - CCME, 2002; c - OMEE, 1993; d - ANZECC, 2000.							

Soil pH further explained the changes in aquatic pH levels for it recorded the lowest pH of average 5.41 (Table 7). However, the values did not differ significantly between the two seasons and this was expected for rising or lowering soil pH does not happen overnight (Table 7). In the specific cane farms, the pH differed significantly from the football pitch used as a control implicating agronomic inputs in sugarcane farming over the increase (Table 7). However, this is expected as some of the agronomic inputs such as nitrogenous fertilizers have the potential of lowering soil pH through nitrification processes (equations 1 and 2)

$(NH_4)_2CO + 4O_2 = 6H^+ + 2NO_3^- + CO_2 + H_2O$ ....1 (Urea)

$(NH_4)_2HPO_4 + 4O_2 = 3H^+ + 2NO_3^- + H_2PO_4 + 2H_2O$ .... 2 (DAP)

Total hydrogen ions produced from this reaction are capable of lowering soil pH over time. The pH situation in this study is no different from other sugarcane growing areas with most Australian farms registering an average soil pH of 6.5, Taiwan 6.5 and South Africa 6.0 as reported by Zueng-Sang (2000) (Table 7).

This soil pH values are of major concern in sugarcane fields as they have the potential of affecting the solubility of naturally occurring and arthropogenically added heavy metals hence making them bioavailable to plants and transportation to aquatic systems (Alloway, 1995). The situation was vindicated with high heavy metal levels being recorded in both river water and canal waters (Tables 3, 4, 5 and 6). It is important to mention that these high values of heavy metals reported in this study in water, sediments and soils seem to be of natural origin in this area as was shown from the lack of significant difference of the values in soil from cane farms and the control farm (Table 7).

Table 7: Mean seasonal variations of heavy metals in surface soils from sugarcane farms traversed by River Kuywa within Lake Victoria basin (dry weight).

	Element (mg/kg)	pH	% Silt	%TOC	Cd	Cu	Zn	Pb	Cr
Dry season	1. Football pitch (control)	**7.46**	**16.45**	**4.76**	**2.82**	**63.68**	**123.49**	**58.54**	**116.20**
	2. Tree plantation farm	6.62	15.26	6.24	3.10	46.01	120.32	56.08	90.20
	3. Factory premises	5.08	17.98	7.28	3.35	83.36	134.39	53.21	130.05
	4. Newly cultivated farms	5.34	23.43	6.60	2.16	75.95	132.02	55.00	147.85
	5. Farms with mature cane	5.25	16.78	9.35	4.24	71.08	116.11	63.41	184.66
	6. Farms with 1 months cane	5.27	23.67	10.89	5.33	93.52	104.34	63.38	143.53
	7. Farms with 3 months cane	5.15	28.89	10.67	6.84	84.51	110.71	71.09	178.95
	8. Farms with 5 months cane	5.54	32.43	9.4	3.73	67.31	96.02	51.66	160.98
	Dry season mean	**5.46**	**21.86**	**8.63**	**4.11**	**74.53**	**116.27**	**59.12**	**148.03**

	1. Football pitch (control)	**7.16**	**17.00**	**5.00**	**2.67**	**66.10**	**114.67**	**50.68**	**96.89**
	2. Tree plantation farm	6.82	15.34	7.34	2.25	51.55	119.95	55.59	86.42
Wet season	3. Factory premises	5.18	17.67	8.24	2.50	83.33	186.34	51.32	130.29
	4. Newly cultivated farms	5.34	22.89	6.35	3.20	90.62	154.86	49.99	161.58
	5. Farms with mature cane	5,15	17.00	5.17	4.04	81.45	152.45	51.60	186.59
	6. Farms with 3 months cane	5.27	21.87	11.27	2.63	75.33	182.65	52.05	145.95
	7. Farms with 5 months cane	5.05	30.87	10.38	4.67	57.09	161.38	36.18	171.05
Statistics	8. Farms with 7 months cane	5.54	28.98	8.43	6.50	65.64	154.05	55.32	134.63
	Wet season mean	**5.36**	**21.45**	**8.43**	**3.68**	**72.14**	**158.81**	**50.30**	**145.22**
	LSD site dry season $p \leq 0.05$	0.09	1.23	1.76	2.38	6.12	8.32	4.45	9.97
	LSD site wet season $p \leq 0.05$	0.12	1.45	2.02	1.81	5.21	18.62	9.96	10.87
	LSD seasons mean $P \leq 0.05$	0.32	2.32	3.34	3.22	7.23	10.54	3.45	7.98
	CV%	21.34	23.45	24.67	25.21	23.34	26.76	25.95	22.68
Stds	Intervention values in this soils (Ib)*	NG	NG	NG	0.69	31.00	121.95	73.95	87.00
	A,B,C values for Taiwan stds$^{\$}$	NG	NG	NG	2, 4, 5	100, 250, 200	120, 300, 500	50, 300, 500	100, 250, 400
	Critical level in soils$^{\#}$	< 5	NG	NG	75 - 100	60 – 125	70 - 400	100 - 400	75 - 100
Other studies	Taiwan standards (Is)$^{\$}$	< 5	NG	10.00	0.80	36.00	140.00	85.00	100.00
	Australia$^{\$}$	6.5	NG	NG	1.00	100	200	150.00	100.00
Key:	Taiwan$^{\$}$	6.5	NG	NG	1.74	20.30	180.00	32.60	43.20
	South Africa$^{\$}$	6.0	NG	NG	2.00	100.00	185.00	56.00	80.00

NB: Dry season sampling done in February and wet season sampling done in May 2009; LSD – Least Significant Difference; CV%: percent coefficient of variation in replicated samples; * - this is a modified value using the formula: Ib = Is ((A +B %silt + C %TOC) /

	(A +25B +10C)), Where: Ib – is the modified intervention value for this soils, Is – is the intervention values for a standard soil that is 10% TOC and 25% silt, A – the upper limit of the background concentration, B – monitoring level, C – the intervention level at which pollution control is needed. (Zueng-sang, 2000). $ - Zueng-Sang, 2000; # - Alloway, 1995.

Reduction in pH is not the only culprit in increasing bioavailability of heavy metals but also increase in organic carbon of soil/sediment has been identified to enhance heavy metal bioavailability for both plant uptake and mobility from soils to aquatic systems (Antoniadis and Alloway, 2001). The current research reveals that sugarcane farming increased the levels of organic carbon content in soil and sediments as is evidenced from statistically different values in cane soils/sediments and their controls (Table 5, 6 and 7). It is therefore not surprising to find elevated levels of heavy metals in both canals and river systems.

Considering each metal variation specifically, it was noted that Cd levels did not differ significantly between the dry and wet seasons of river water levels (Table 3). However, in both seasons, Cd levels differed significantly in River Kuywa water before the sugarcane farms and after the sugarcane farms with higher values in the latter suggesting sugarcane farming to have a positive impact on the levels of this metal. Canal water registered similar trends with the values being higher than River water (Table 4). Cd levels in canal water differed significantly from the control canal implicating agronomic inputs in sugarcane farming over the increase. However, different farming activities affected the levels differently as is evidenced by the significant differences in Cd levels between different canals draining water from sugarcane fields with different farming activities (Table 4). Water in canal 2 draining water from the factory premises registered the lowest values from other canals indicating that the increase in the metal levels was due to agronomic inputs in sugarcane farming and not processing.

Considering the aquatic system, cadmium levels were beyond Canadian standards in water (Table 3 and 4) and beyond chronic level with respect to USEPA standards (Table 4) in both the river and canals. With respect to sediments, the behavior in cadmium levels variations was similar to water levels but with sediments registering higher values (Tables 5 and 6). Although the results of the current study indicate that cadmium levels were above internationally set limits for sediments, there is need to determine toxicity levels due to cadmium to benthic organisms using toxicity models like equilibrium partitioning model and narcosis theory (USEPA 2005) for unbiased conclusive recommendation to be made. This is due to the fact that this research did not determine binding phases for heavy metals like sulfide, iron and manganese neither did it extract the metals simultaneously for comparison with acid volatile sulfide (USEPA, 2005).

However, cadmium levels in the soils within the studied region were well over the calculated intervention levels putting in consideration the percent silt and organic carbon for these soils (Table 7; Zueng-sang, 2000). The values were above other sugarcane regions suggesting this area to be having high amounts of these metals that calls for immediate intervention (Table 7). It is therefore extremely important for this region to control the lowering of soil pH in order to avoid aquatic systems being contaminated by bioavailable heavy metals to unacceptable levels.

Other Heavy metals studied Cu, Zn, Cr and Pb had no different behavior from cadmium values prompting the conclusion that agronomic inputs in sugarcane farming affected heavy metal levels in aquatic systems within these zones and to a larger extent their sinks like Lake Victoria in the present case. The main impact of the agronomic inputs was found to be the lowering of soil pH that further aided in conversion of the naturally occurring heavy metals to bioavailable mobile forms that through surface runoffs, soil erosion and leaching found their way into aquatic systems.

Recommendations

It is recommended that actions be put in place to raise the soil pH in the studied area and those other sugarcane growing fields in Lake Victoria catchment to follow suit.

Use of sewage sludge and other organic oriented fertilizers should be reconsidered to avoid increasing organic levels of the soils since this also increases bioavailability of the naturally occurring heavy metals in this region.

Toxicity tests to be done in the studied area to determine if benthic organisms are being negatively affected with the high reported levels of heavy metals.

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