Sediment Production from Settlements and Farmlands within Lake Victoria Shoreline Zone in Uganda and Tanzania

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Summary

In spite of the general acceptance that the current land use changes are unlikely to yield a sustainable environment, the source of sediment that causes eutrophication in Lake Victoria is not clearly understood. It is hypothesized that roads, footpaths, and compounds (settlement) are a major source of sediments. This study was conducted on the northern Lake Victoria shoreline to determine the rate of sediment generated by agricultural and settlement land use types. Results show that settlements generate significantly higher sediment yields i.e. between 17-87 ton.ha^{-1}. yr^{-1} whereas agricultural land use types produced between 0-27 ton ha^{-1}.yr^{-1}. The high sediment yield from settlements is attributed to high runoff coefficients and the occurrence of gully erosion. The high sediment yield from settlements justifies the need to conduct further investigations on the contribution of settlements to sediment production in catchments with different soil - landscape and climatic setting in the Lake Victoria catchment.

Résumé

Production de sédiments provenant des aménagements du territoire et des terres agricoles dans la zone de rivage du lac Victoria en Ouganda et en Tanzanie

Malgré l'acceptation générale que les changements d'utilisation de terre sont peu probables de produire un environnement durable, la source de sédiment qui cause l'eutrophication dans le Lac Victoria n'est pas clairement connue. Il est supposé que les routes, les trottoirs, et les aménagements du territoire constituent une source majeure de sédiments. Cette étude a été conduite sur le rivage de Lac Victoria pour déterminer le taux de sédiment produit par l'agriculture et ces autres types d'utilisation de la terre ou aménagements du territoire. Les résultats montrent que les aménagements du territoire produisent significativement les plus grandes productions de sédiment c-à-d entre 17-87 ha de tonne^{-1}.an $^{-1}$ tandis que l'agriculture produit entre 0-27 ha de tonne^{-1}.an^{-1}. La haute production de sédiment produite est attribuée aux coefficients élevés de ruissellement et d'événement d'érosion de caniveau. Le haut rendement de sédiment généré des aménagements du territoire confirme le besoin de conduire des investigations ultérieures sur la contribution des aménagements du territoire à la production de sédiment dans les captages avec des autres types de sol - le paysage et le cadre climatique dans le captage de Lac Victoria.

Introduction

Eutrophication of Lake Victoria, among others, has been identified as a major issue contributing to lower Lake Ecosystem productivity (10, 18). Whereas the impact of eutrophication on various Lake ecosystem functions and productivity has been quantified and well documented (1, 3, 9, 13, 23, 26), the source of nutrient load remains a controversial issue. Nutrient laden sediments, among others, are major pollutants of lake waters. Whereas eutrophication is confined to major urban areas around the lake shore (16, 18, 24, 31), rural areas have also taken the blame for sediment loading into Lake Victoria (9, 29, 30).

Studies on sediment yield in Lake Victoria basin are based on erosion models and soil loss data from runoff plots in agricultural fields (2, 4, 11, 17 19, 23). Data on soil loss from settlements in the Lake Victoria catchment is lacking yet settlements are associated with gullies (11) that are a major source of sediment (5).

It is hypothesized that roads, footpaths, and compounds (settlement) are a major source of sediments. Findings can direct intervention and policy to focus on roads, footpaths and compounds in addition to the crop fields. This study was conducted to determine

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the rate of sediment production in agricultural and settlement land use types in 2 representative micro-catchments in northern and southern Lake Victoria shoreline.

Materials and methods

The study was conducted in Iguluibi (ca. 20 km^2) and Magu (ca.12 km^2) micro-catchments situated on the northern and southern shoreline of Lake Victoria in Uganda and Tanzania respectively (Figure 1).

Iguluibi micro-catchment (Uganda) is characterized by a bimodal rainfall pattern with a mean annual precipitation of 1283 mm (12). The major soil types are very deep, sandy clay loam Luvisols on a side slope of a ridge in an undulating topography with average slope of 8%. The structure of the top soil is moderate sub-angular blocky with low organic carbon and available phosphorus levels. Soil exchangeable potassium is high with pH values of medium rating.
The cation exchange capacity is low with the base saturation ranging from medium to high (Table 1).

Magu micro-catchment, is located in Simiyu – Duma river catchment (Tanzania) that is characterised by a unimodal rainfall pattern with a mean annual

Table 1
Soil physical and chemical properties for the soil type in Iguluibi, Uganda

Depth (cm)	0 - 22	22 - 51	51 - 80
Clay (%)	20	38	44
Silt (%)	15	11	7
Sand (%)	65	51	49
pH H_2O 1:2.5	5.8	5.9	5.0
Organic Carbon (%)	1.8	1.0	0.9
Avail. P Bray (mg/kg)	6.0	7.0	6.0
CEC NH_4OAc (cmol(+)/kg)	14.5	10.3	10.3
Base saturation (%)	51	71	68
Exch. Ca (cmol(+)/kg)	5.4	5.4	5.2
Exch. Mg (cmol(+)/kg)	1.2	1.1	1.2
Exch. K (cmol(+)/kg)	0.7	0.7	0.5
Exch. Na (cmol(+)/kg)	0.1	0.1	0.1

Source: Land Evaluation around Lake Victoria (11).

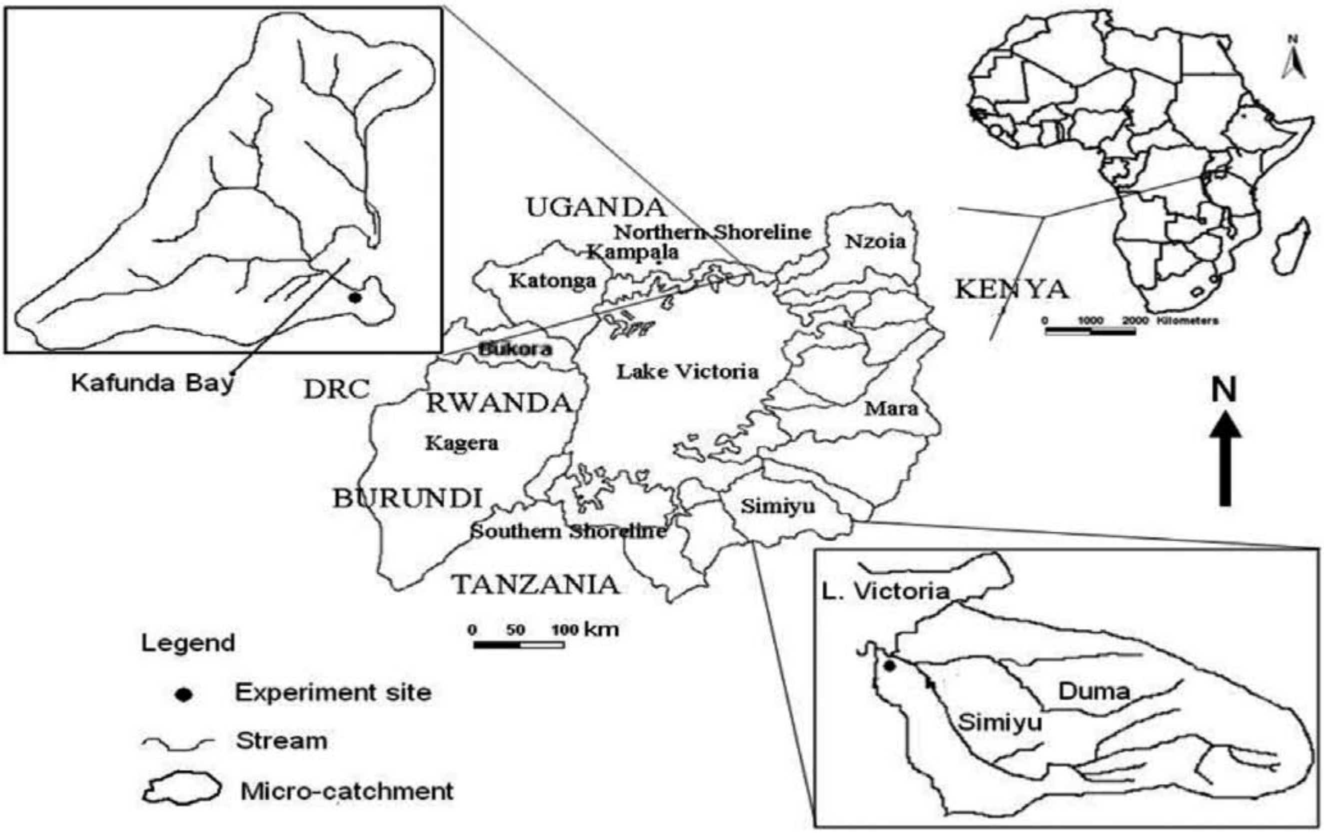

Figure 1: Location of micro-catchments where sediment yield measurements were done in Uganda and Tanzania.

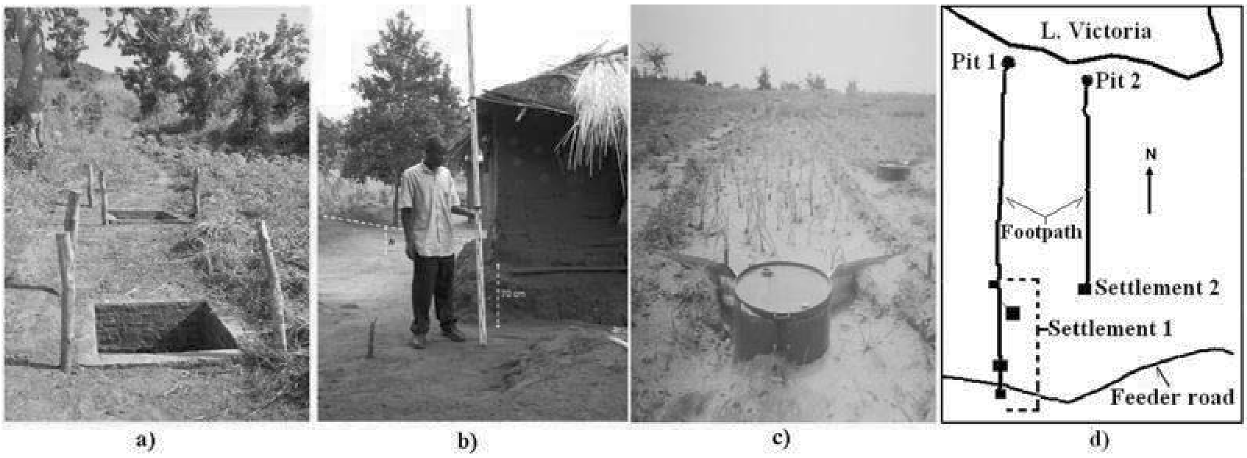

Figure 2: a) Catch-pits position along foot-paths; b) An eroded compound; c) a Gerlach trough placed to trap runoff from a plot; d) sketch map for catch-pit, path and compund connectivity.

precipitation of 800 - 1200 mm. The soils have sandy topsoils underlain by heavy sandy clays (*Regosols*) associated with Vertisols and Leptosols as inclusions on an undulating topography with average slope of 8%. *Vertisols* are associated with flat depressions in the landscape. *Arenosols* are located on lake terraces (15).

The pH is close to neutral (6.6 - 6.9) for the *Regosols* and Vertisols with the exception of *Arenosols* which are strongly acidic (5.1). The organic carbon content and exchangeable potassium are low (Table 2). With the exception of *Regosols* with a high level of available phosphorus, the levels are low for the *Arenosols* and Vertisols.

The cation exchange capacity is low for the Arenosols but high for the Regosols and Vertisols. The base saturation is low to medium for the *Arenosols* and high for the Regosols and Vertisols.

Gerlach sediment troughs (120 liters) were used to measure sediment yield from runoff plots (2 m x 20 m) in three replications under various land use types for the year 2005. Land use types investigated in Iguluibi included: sugarcane, coffee, millet, ground nuts, sweet potatoes, bananas, maize, maize+cassava+sorghum intercrop, and cassava. A mature plant crop of sugarcane; a 20 year old coffee plantation in an agroforestry setting with slashing as key weed control practice; millet, ground-nuts, sweet potatoes, maize, maize+cassava+sorghum intercrop, and cassava crops monitored throughout the growing period with hand hoe land opening and weed control practice.
Land use types investigated in Magu included rice, cassava, maize, and cotton.
The plots were farmer managed.

Sediment ($t.ha^{-1}.yr^{-1}$) and runoff water (liters $ha^{-1}.\ yr^{-1}$) were collected during the year 2005 for Uganda and during the period October 2004-March 2005 for Tanzania (Table 3). Seventy three and 38 rainy days were recorded for Uganda and Tanzania respectively. Samplings were done on rainy days only (Table 3). Twenty three samplings were carried out for Uganda and 21 were done for Tanzania.
Sediment yield in catch-pits was monitored in Uganda

Table 2
Soil physical and chemical properties for the soil types in Magu, Tanzania

Soil type	Regosol		Arenosol		Vertisol	
Depth (cm)	0 - 30	30 - 90	0 - 35	35 - 75	0 - 40	40 - 100
Clay (%)	27	37	12	8	44	51
Silt (%)	10	12	9	6	23	21
Sand (%)	63	51	79	86	33	28
pH H2O 1:2.5	6.6	6.9	5.1	5.1	6.9	7.8
Organic carbon (%)	0.9	0.7	0.6	0.6	1.3	1.0
Avail. P Bray (mg/kg)	35.5	11.4	4.2	0.4	13.2	30.9
CEC NH4OAc (cmol(+)/kg)	19.0	32.6	8.2	9.8	34.8	34.2
Base saturation (%)	65	55	21	17	70	79
Exch. Ca (cmol(+)/kg)	8.9	14.4	0.7	0.6	16.4	16.6
Exch. Mg (cmol(+)/kg)	2.9	2.9	0.5	0.5	4.5	3.8
Exch. K (cmol(+)/kg)	0.16	0.18	0.13	0.19	0.5	0.32
Exch. Na (cmol(+)/kg)	0.37	0.60	0.42	0.38	2.95	6.37

Source: Soils and landscapes report March – April 2005 (15).

only since the nature of the footpaths in Tanzania did not allow proper placement of catch-pits. Sediment yield was monitored over a period of one year – 2005. Two footpaths, 80 meters apart, one connected to four compounds (Settlement 1) and the other to one compound (Settlement 2) were selected for sediment yield monitoring using catch-pits. The drainage area for the catch-pits 1 and 2 are 0.25 and 0.09 ha respectively and it is a total measure for the compounds and footpath including sections of the feeder road draining to the catch-pit (Figure 2).

Results

Table 4 and figure 3 indicate that sediment yield from runoff plots in the gardens ranges from 0 - 27.3 $t.ha^{-1}$.

Table 3
Monthly total rainfall and rainy days during the sediment and runoff monitoring period in Uganda (2005) and Tanzania (2004 -2005)

Year	Month	Rainy days	Rainfall (mm)	Rainy Days	Rainfall (mm)
2004	October			3	28.8
	November			7	59.9
	December			10	144.5
2005	January	5	60.1	6	185.3
	February	2	8.2	6	44.3
	March	10	134	6	123.3
	April	8	166.8		
	May	11	269.3		
	June	9	123.3		
	July	3	74.4		
	August	7	223.6		
	September	8	128.7		
	October	6	114.3		
	November	4	76.2		

A rainy day is counted if rainfall exceeds 0.2 mm (20).

Table 4
Mean annual sediment yield (t^{-1}. ha^{-1}) measured on plots within various land use types in the Ugandan shoreline of Iguluibi

Land use (2005)	N	Mean	Median	SD	Min	Max
Agriculture_						
Bananas	3	2.1	0.0	4.3	13.4	0
Cassava	3	27.3	8.7	37.9	0.2	138.8
Cassava maize sorghum intercrop	3	8.5	7.7	11	0	41.6
Coffee	3	0	0	0	0	0
Groundnuts	3	4	0.0	12	0	40
Maize	3	2.6	0.2	5.2	0	15.6
Millet	3	0.7	0.03	1.7	0	6.9
Sugarcane	3	0	0	0	0	0
Sweet potatoes	3	1.1	0.2	2.6	0	10.4
Built up		Cumulative yield ($t.ha^{-1}$)	Mean yield ($t.ha^{-1}$)			
Settlement 1(Mean compound area = 0.25 ha)	1	87	52			
Settlement 2 (Mean compound area = 0.09 ha)	1	17				

N= Number of plots / path where sediment yield was measured during the year of 2005.

Table 5
Mean annual sediment yield ($t.ha^{-1}$) measured on plots within various land use types in the Tanzanian shoreline of Magu

Land use (2004 – 2005)	N	Mean	Median	SD	Min	Max
Rice	3	1.2	1.0	0.4	0.6	2.2
Cassava	3	7.9	6.3	4.8	1.3	19.5
Maize	3	15.6	13.8	5.8	6.7	29.1
Cotton	3	22.7	20.3	9.6	10.5	50.9

N= Number of sediment plots where sediment yield was measured during the year of 2004 - 2005.

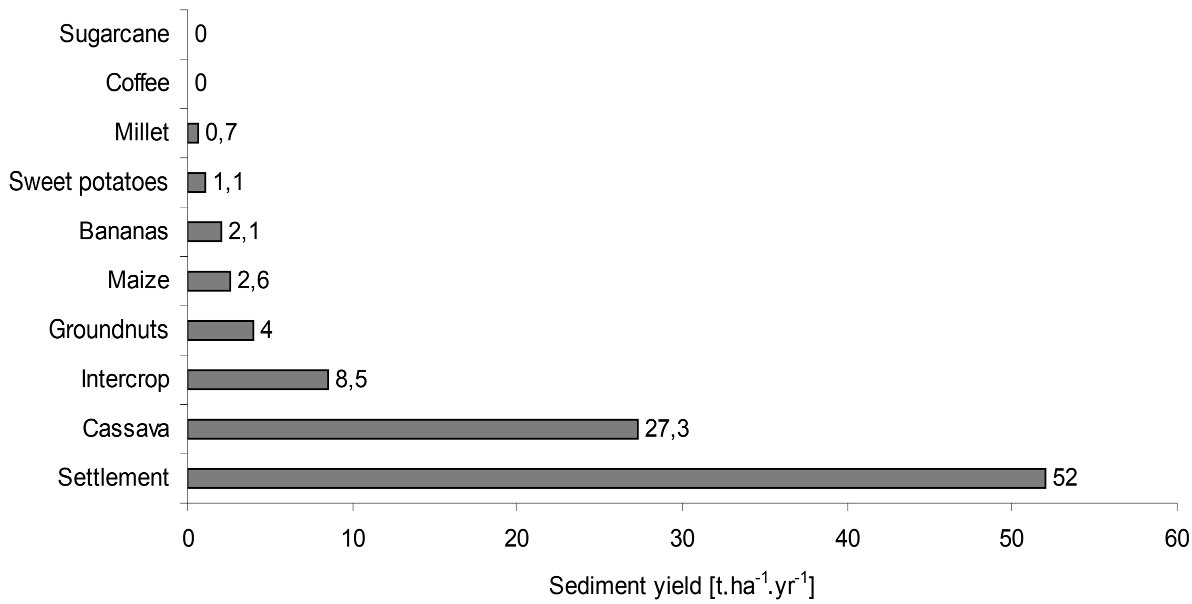

Figure 3: Mean sediment yield measured for various land use types in the Ugandan shoreline of Iguluibi. Intercrop= Maize + Cassava + Sorghum intercrop.

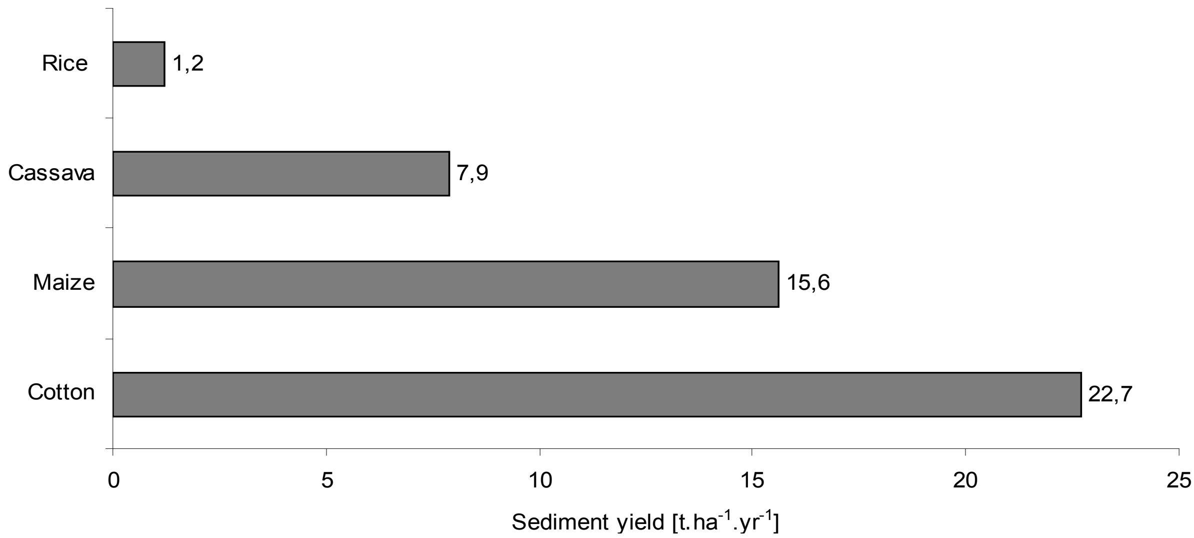

Figure 4: Mean sediment yield for various land use types in the Tanzanian shoreline of Magu.

yr^{-1} with cassava generating the highest rates of 27.3 $t.ha^{-1}.yr^{-1}$ in the Ugandan shoreline of Iguluibi. The mean sediment yield from runoff plots equals 5.1 $t.ha^{-1}.yr^{-1}$. Table 5 and figure 4 depict sediment yield from runoff plots in the gardens in a range of 1.2 - 22.7 $t.ha^{-1}.yr^{-1}$ with cotton, unlike cassava in Uganda, generating medium rates (12 - 25 $t.ha^{-1}.yr^{-1}$) of sediment yield in Magu, Tanzania.

On the other hand, according to FAO (6) soil loss categories, medium to very high levels of sediment yield (i.e. 17 - 87 $t.ha^{-1}$) were observed under settlement land use types (Table 4). The number of settlements connected to a footpath is shown to affect sediment yield significantly as shown in table 4.

Discussion

Sediment yield rates obtained in the gardens are similar to those measured on runoff plots else where in the Lake Victoria catchment of Uganda (Table 6).

Mean soil loss from runoff plots in the gardens is high to very high (0.2 - 138.8 $t.ha^{-1}.yr^{-1}$) under cassava and the settlements (52 $t.ha^{-1}$).

Table 6
Mean annual soil losses by water erosion measured on runoff plots or predicted using the USLE in the Lake Victoria catchment of Uganda

Land use	Soil loss ($t.ha^{-1}.yr^{-1}$) Approach		Source
	Measured	Predicted (USLE)	
Annual crops		2.0 – 9.0	4
Annual crops	17.0 – 86.8	74.4 – 93	2, 17, 19, 23,
Rangelands	3.2 – 53.2	52 – 91.5	23, 19
Coffee	19.6 – 44.9	38.0	19, 23
Banana	25.1 – 27.9	21.3 – 32	17, 23, 19
Banana-Coffee intercrop		26.6	23

The high rate of sediment yield observed under cassava in Uganda and cotton in Tanzania and from the settlements in Uganda call for soil conservation practices that ensure complete surface cover and encourage soil structure improvement to enhance infiltration are in place. This in turn minimizes soil erodibility through increased resistance to detachment and transport of soil particles.

Observed rates of soil loss are low (< 12 $t.ha^{-1}.yr^{-1}$) for most crops with the exception of cassava (Uganda) and cotton (Tanzania). They fall within the tolerable range that varies from 1 to 12 $t.ha^{-1}.yr^{-1}$ (25) and 5 $t.ha^{-1}$ yr^{-1} estimated for some soil types in Uganda (2).

Mean sediment yield of 52 $t.ha^{-1}$ from settlements reflects the underestimation of sediment yield using extrapolated results from runoff plots and predictions by various models especially USLE that are widely used in Africa (25) and also embedded in models used to predict sediment yield at basin scale (5). Both approaches determine and predict rates of soil loss based on rill and inter-rill soil erosion processes leaving out the gullies that are commonly associated with household compounds, roads and footpaths (11). It is also evident that sediment yield measurements at one scale are not representative for sediment yield at another scale (5). The limitations with these approaches has been extensively reviewed by de Vente and Poesen (5) and observed by Morgan (21) and Roose (25).

Thomas (28), while working in the northern fringe of Lake Victoria, observed that soil erosion is not marked in the centre of the gardens and that any soil washed down is retained in the cultivated zone (gentle long back slopes). He however noted that erosion takes place in three places – first, on the bare ground near the houses; secondly, on the footpaths running down to the waterholes at the base of the hill; and thirdly in the ditches, which are sometimes nearly 1 m deep, cut down the sides of cultivated plots to prevent invasion by the rhizomes of *Digitaria scalarum*. He also observed that the soil is of the type resistant to erosion and is typical of that covering much of the slopes in the northern fringe of Lake Victoria; it consists of a red-brown loam, about 20 cm deep, over a red clay.

It is important to note that not all sediment produced in the gardens and the settlements ends up into the lake. Most of it is redeposited in the gardens and the wetland papyrus that act as natural silt traps (7, 8). The very high rates of soil lost from settlements threathens the existence of papyrus vegetation in the wetlands as excessive sediment is likely to clog the papyrus thereby reducing its capacity to filter sediments.
The significant difference in sediment yield rates between one (17 $t.ha^{-1}$) and two (87 $t.ha^{-1}$) compounds reveals the negative consequences of increased sediment production that may be associated with rural urbanisation due to population increase. Households have increased from 3 in 1936 to about 200 households in 2000 in Iguluibi. Fishing villages increased from one to eight during the same period (14).

Rates of sediment yield measured under field crops in this study are generally lower than those measured and predicted within the Lake Victoria catchment (Table 6) possibly because all factors involved were estimated using different indices. These differences also reflect the variation of factors that influence soil erosion (extensively reviewed by Roose, 25) across the lake catchment. Such factors include slope type and shape, extent and thickness of mulch in banana fields, rainfall erosivity and soil erodibility. It is a challenge faced when there is a need to extrapolate or scale up results from plot to catchment level. It therefore calls for a need to zone the catchment into sub-catchments with similar geo-hydrological characteristics (21, 27) within which interpolations can give a more realistic estimation of soil loss and therefore sediment yield.

The generally low rates of sediment yield (< 12 $t.ha^{-1}. yr^{1}$; 6) observed in the crop fields is explained by the deep porous sandy clay loams characterised by high (144 $mm\ hr^{1}$) infiltration rates observed (11). Sugarcane, coffee plus bananas in addition to the canopy cover, are associated with mulch that completely covers the soil, thereby minimising runoff and erosion. In Tanzania, cassava is planted on ridges made on moderately deep sandy soils. This high textural porosity explains the low rates of soil loss observed under cassava in Tanzania compared to Uganda.

Conclusions

The nature of the field parcels, and overall farming techniques in the riparian zone of Lake Victoria has an overall effect of protecting soil structure against raindrop impact, encouraging water infiltration, obstructing runoff and therefore minimizing sediment yield i.e.< 12 $t.ha^{-1}. yr^{-1}$ from the gardens. However, the presence of settlements is associated with very high rates of soil loss (i.e. 17-87 $t. ha^{-1}$), an indication that future unchecked expansion of settlements is likely to contribute greatly to sediment yield and therefore the likely sedimentation of Lake Victoria.
Although aquatic weeds are effective buffers against sedimentation, excessive sedimentation is likely to reduce the filtering capacity thereby rendering Lake Victoria vulnerable to pollution.

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