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Influence of land use/cover on water quality in the River Sironko catchment area, Eastern Uganda.

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Abstract:
Ten sampling stations located on RiverSironko catchment area were used to assess the contribution of selected land uses to the nutrients and Physico-chemical water quality levels of river Sironko for a period of six months from November 2019 to April 2020. This was done so as to capture wet and dry seasons. The data was also used to examine whetherland use size, altitude and discharge had an impact on water quality in the catchment area. The catchment area was divided into the upper, middle and lower reaches. Based on visual interpretation of Google Earth map and field observation data, polygons for the reference land use classes of forest, agriculture, sand mining, industrialization, and urbanisation that contributed their run off to the catchment were created using "heads up" digitizing tools in Google Earth program and sizes were calculated. The water quality parameters from land uses were compared with land use size, altitude and discharge usingPearson correlation coefficients generated from STATA Version.14in each of the three reaches to show the magnitude of impacts of land uses. Results indicated that water quality levels in the upper reaches were better than in the middle and lower reaches of the catchment area. Land use size had a significant negative correlation with TDS at p(0.0135) but with significant positive correlation with D.O at p(0.0056) in the middle reaches. In the lower reaches, land use size had a significant correlation with nutrients at p(0.0344 – 0.0015). In the upper reaches, altitude and discharge influenced water quality more than land use size. We recommended that, all homesteads and business establishments must have toilets at least 10m away from the river banks.
Key words: *E-Coli, protected area, river reaches, land use area.*

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I. Introduction

Rivers are a main source of water for human's domestic use, animal consumption and support aquatic biodiversity. NEMA (2004), emphasized that all natural aquatic resources in Uganda belonged to the government as this would enable it manage them well. Communities and individuals who own land in Sironko catchment area extending up to the river banks use it according to their wish leading to un controlled spontaneous distribution of land use activities such as agriculture, sand mining, urbanisation, industrialization, and forestry among others along the river most of which seem to cause deterioration and impairment to the river water quality (Kasangaki*et al.,* 2008) evidenced by siltation, drying up of some river tributaries and water color changes. Previous studies such as one by Kobing*et al.,* (2009) ontwo rivers in Kenya, Raburu et al., (2002) on river Nyando in Kenya, Bagalwa*et al.*, (2014) on tributary Rivers feeding L.Albert in DRC and Uganda, Kasangaki*et al.,* (2007) on Bwindi forest streams in Uganda have assessed the spatial and temporal trends of water quality levels in relation to different land uses. These have concentrated on different environments from the Mount Elgon region in Eastern Uganda and have not only concentrated on one or two land uses but also have covered partial catchments. No research has yet been carried out on River Sironko to show how different land uses are affecting the water quality levels over time and space yet the situation seems to be deteriorating with time more than ever before. If this situation of land use impact is not checked early enough, ecosystems will deteriorate further and diseases will affect humans (Hyman, 2018). SDGs for (2030) number six (6), emphasize clean water and sanitation by protecting water resources which is best done by controlling the nature of land uses in catchment areas so that the most inappropriate land uses that affect water quality can be eliminated or modified. This elimination or modification can only be done when data about impact of each land use on water quality in the whole catchment area of Sironko is available.

II. Materials And Methods

2.1 Study area;

River Sironko catchment is located in Eastern Uganda stretching between 33.5 ^{0} – 36^0 E and 1^0 – 5^0 N. It drains into Lake Opeta-Kyoga basin. The catchment covers a surface area of approximately 710.96 KM^2, with its waters flowing over a distance of approximately 97.10Km. River Sironko headwaters originate from the slopes of the northern part of the Mount Elgon range (approximately 3300 m a.s.l). The biggest part of relief is mountainous with interceptions of gentle slopes westwards. The river and its tributaries flows northwest wards, crossing several towns such as Makuyu, Budadiri, Sironko, simu corner and Muyembe-Nabbongo.

In the upper most reaches, River Sironko originates from a natural tropical forest in its headwaters. This is conserved as both Mount Elgon National park and a forest reserve. It also crosses cultivated steep slopes where perennial crops are grown (coffee and bananas), animal grazing and a regional coffee collection centre that also hosts a coffee processing factory at the same site. In the middle reaches, it crosses both perennial and some annual crop gardens, sand mines as well as residential areas and some urban centres at levels of town boards and town councils like those already mentioned above while the lower reaches are dominated by both annual and perennial crop gardens of banana and sugar cane plantations and wetland part of which is used for animal raring. With a growing population size of 242421people (Uganda Bureau of Statistics, 2017), the R. Sironko is exposed to typical local urban impacts. The catchment comprises a variety of climatologically and ecologically different regions, ranging from a year-round wet climate in the source area of the steep Elgon mountains (2000-3000 mm annual rainfall), over a wet climate with two short dry seasons per year (1400 mm annual rainfall) in the mid-range regions of the system, to the drier downstream region (1000 mm annual rainfall) with pronounced dry and wet seasons. Depending on altitude and season, mean temperatures from source to mouth areas may vary from below 10 °C to over 22 °C. (NEMA,2004).

2.2 Sampling stations:

In the upper reaches, land uses considered were; natural forest conservation, animal grazing and arable farms (mixed agriculture) on River Sipi and Chebonet and industrialization mainly (coffee factory) on R. Kabiriro. Urbanisation, planted forest at Makuyu and sand mining at Budadiriwere considered in the middle reaches. The lower reaches considered Banana plantation, urban centre at Nabongo and sugarcane plantation at Muyembe. Sampling pointswere selected on the basis of at the 'beginning, inside and at the end of land use' on sites indicated on the map shown in Fig. 1.

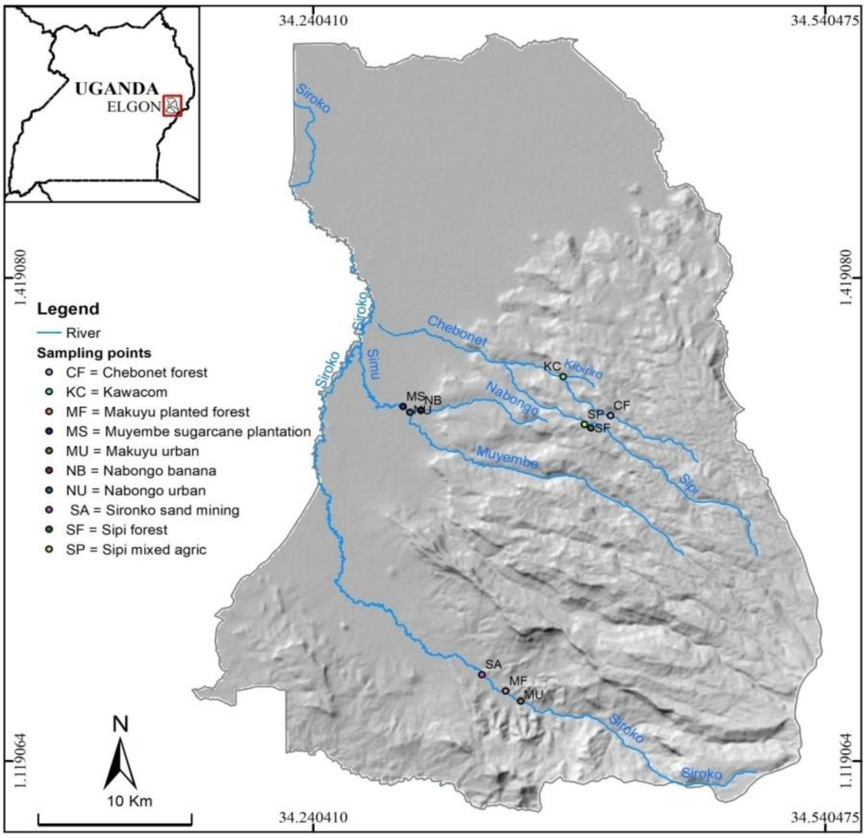

Fig 1: map showing sampling stations in the Sironko catchment area.

2.3 Methods:

Ten sampling sites were selected from upper, middle and lower reaches of RiverSironko catchment area to represent four river orders (table1), human and natural or local factors influencing nutrient and limno – chemical water quality. Various parameters were analysed in the following ways; Samples were picked before the river entered a particular/selected land use (upper edge), in the land use and at the end of the land use. Key physico - chemical parameters that were sampled include; pH, Total suspended solids(TSS), transparency(transp), temperature(temp), salinity(sal), Electrical conductivity(Ec), Total dissolved solids(TDS), Biochemical oxygen demand(BOD), Dissolved oxygen(DO), phosphates, Nitrate and *E.coli.* Water samples were collected using 500ml sterile plastic bottles for later ex-situ quality determination of nitrates, phosphates, *E-coli*, Biochemical oxygen demand and Total suspended solids. Collecting bottles were first rinsed in the stream then submerged at 5- 10 cm to fill up and then sealed, ensuring no visible air bubbles present inside the sealed bottles. Sealed bottle samples were immediately refrigerated (put in a container having ice) and taken to Busitema University Biology laboratory for analytical services within one day following the standard procedures outlined by APHA (1992). The parameters that were analysed in situ include;

i) Electrical conductivity, Total Dissolved Solids, Temperature and pH

The researcher measured Electrical conductivity, Total Dissolved Solids, Temperature and pH by reading directly on the combined HI-991300 Waterproof pH, EC, TDS and Temperature meter of Hanna type. The meter registers the value of Ecin a micro Siemens per centimeter, ppm of TDS as well as ^{0} C for temperature. The probe was immersed into sampled water in a bottle of 500-1000ml and stirred for a short time, after the water stabilized, the button or mode function was pressed and a direct reading was taken. The probe was then rinsed on taking the reading from each sampled bottle for the different parameter listed here. This was to avoid transfer of contamination from one sample to another.

ii) Transparency/light penetration in water was determined by lowering a circular disc called secchi disc which is 20-30cm in diameter and colored black and white sections on a calibrated cable into the water until it disappeared and re-appeared. The reading was recorded as depth of transparency in centimeters measured using a tape measure.

iii) Turbidity

Turbidity was determined by use of Turbidity meter type AL 450T – IR. Measurement began with pressing the ON key, Rinsing out a clean vial three times with the sample to be measured. Filling the vial with the sample and cup ensuring that all outside surfaces were clean and dry. Placed the vial in the sample chamber and aligned correctly. Putting on the sample chamber cover (light shield). Pressing Read Key to start measurement. NTU value displayed on LCD wasread and recorded.

iv) Salinity and Dissolved Oxygen

Salinity and Dissolved oxygen were recorded using the multi-parameter analyzer. The instrument was switch on in a stable temperature environment. The display immediately showed the measured value according to the last calibration. Pressed the lateral arrows to change between the channels until the LCD displayed SAL meaning salinity. The probe was placed in the water sample, then MODE was pressed and the LCD displayed the reading of salinity. Lateral arrows were again pressed until the LCD displayed D.O. The probe was placed in water sample for test of Dissolved oxygen and then the MODE button was pressed to display the reading of D.O in ppm

Land use class area/size was determined by use of GIS techniques. First, GPS coordinates for the location of the reference land uses were captured using a *Germin e60* GPS device during the field survey in the study area. This data was then imported into Google Earth online mappingcomputer application to visualize and delimit the extent of the land uses. Based on visual interpretation of Google Earth map and field observation data, polygons were created for the reference land use classes using "*heads up*" digitizing tools in Google Earth program. Land use type area was then computed from the land use types' polygon sizes. For the natural forest land use type whose cover was more continuous beyond the study area,boundaries were drawn basing on river catchment divides. The main aim of delineating land use was to ensure that the resultant effects were specific to the one inlet-outlet land use effects of a specific land use as described by (Lopez and Nash,2006) in a given sub catchment, reach. The polygons that were based on to calculate the land use size are shown in fig.2

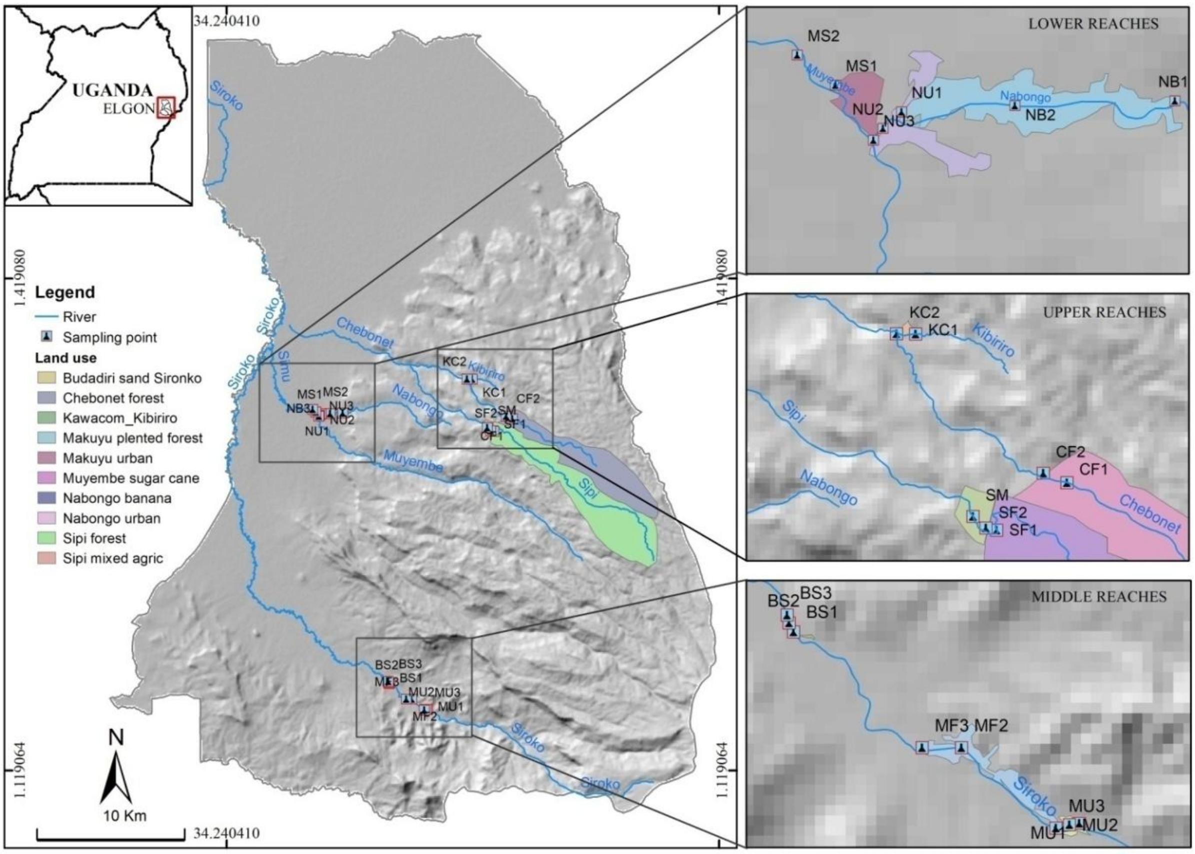

Fig.2: Land use polygons used to calculate land use sizes:

III. Data analysis

In order to determine the relation between land use size, altitude, discharge and water quality parameters across the different sites, Pearson correlation coefficients were generated from STATA Version.14.

IV. Results and Discussions

4.1 Land use/cover in the Sironko catchment area:

A summary ofland use size and other local factors is table as shown in table 1.

Table 1: Land use size and location, altitude, discharge and river orders of the Sironko catchment area:

Land use	Symbol	Easting	Northing	Altitude (m.a.s.l)	Land use size(Km^2)	Rivername and order
Chebonet natural forest	CF	656859.87mE	146166.49mN	2130	2120	Chebonet 1
Sipi natural forest	SF	657645.81mE	147303.15 mN	2072	188	Sipi 1
Sipi mixed agriculture	SP	656711.65 mE	147895.56 mN	2047	73	Sipi 2
Kawacom coffee factory	KC	654476.13 mE	150153.09 mN	1780	5	Kabiriro 1
Makuyu urban	MU	651526.07 mE	127791.08 mN	1287	3	Sironko 2
Makuyu planted forest	MF	651009.41 mE	128231.00 mN	1303	18	Sironko 2
Budadiri sand mining	SA	649005.72 mE	129659.75 mN	1229	1	Sironko 3
Nabongo banana plantation	NB	644978.70 mE	147820.11 mN	1090	28	Nabongo 1
Nabongo urban	NU	644391.39 mE	147735.40 mN	1080	10	Nabongo 1
Muyembe sugarcane plantation	MS	643074.95 mE	1436996.64mN	1084	4	Muyembe 4

Based on the table 1, the study area considered five heterogeneous land uses/covers including forestry, agriculture, industrialization, urbanisation and sand mining in the three reaches.

In the upper reaches we considered natural forest land use in a protected area which acted as our reference site given the fact that it appeared to be in its natural conditions of least human disturbance and the river in this part is in its pristine stage. Here the river merges out of the natural forest in two tributaries namedChebonet and Sipiwhere they originate before joining the main stem River Sironko. In this reach, forestry land use had the biggest land area with 2308Km^2 (for both Chebonet and Sipi sub catchments combined). This land use is however constantly under encroachment by the neighboring communities who keep cutting trees for firewood, and setting the cattle to graze especially on the fringes of the national park. The forest is at the altitude of 2072M.a.s.land above and these two rivers that were studied here are in their order 1.

Mixed agriculture, with cattle farming takes a bigger portion with some annual crop gardens. This starts exactly after the forest and their size is 73Km^{2}while the altitude is 2047M.a.s.l. This is mainly on River Sipi in its order two. The industrialization in this reach was the smallest with only 5Km^2 at the altitude of 1780M.a.s.l and the River Kabiriro on which it is located is also in its order 1. Industrialization here was considered because of the observable impacts of the coffee industrial waste disposal in the stream and the many complaints registered by the residents about the bad smell they get in the water they fetch for home consumption from this stream.

In middle reachesthe main stem R. Sironko was considered and had the largest land usemainly of the planted forest of eucalyptus with 18km^2. The forest engulfs the river for a distance of 5km length and about 2km wide. Its altitude is 1303Ma.s.l.Land the river is in its 2nd order. In terms of land use size in this reach, this is followed by Makuyu urban centre with 3km^2 at an altitude of 1287M.a.s.l in the 2nd order of the river Sironko. In this land use, the river dissects the urban centre almost symmetrically to an extentthat during bankful discharge, some houses are swept away by river water; there is a lot of garbage disposal in the river hence affecting the water quality. The smallest land use in this reach was sand mining with1 km^{2}located at a lower altitude of 1229M.a.s.l and river Sironko here is in its 3rd order. Sand and stones are removed from the running water thereby increasing turbidity of the river

In the lower reaches, the smallestland useconsidered was the sugar cane plantation with only 4Km^2 located at a lower altitude of 1084M.a.s.l. It is on River Muyembe which is one of the Sironko tributaries in 4th order. The sugarcanes are grown up to the river bank leaving no buffer zone. The largest in size was the banana plantation along River Nabongo in its order 1 with 28Km^2 at an altitude of 1090M.a.s.l with only banana plants in pure stands extending up to the river bank stretching for a length of about 6 km and width of about 4km.lastly in this reach is the Nabongourban area which was at a level of a town board at an altitude of 1080M.a.s.lwith an area of 10Km^2. The river surrounds the town on one side and receives effluent from the town which is also a market for agricultural products like sugarcane and banana that are located on the river bank while some latrines are located on the river bank yet some people use this water for domestic use.

4.2 Spatio-temporal water quality changes in the upper reaches of theSironko catchment area:

Data about the Physico-chemical water quality level in the upper reaches was recorded and summarized in table 2below:

Table 2 : Average values for both wet and dry seasons at sites in the upper reaches

		Chebonet natural forest			**Sipi natural forest**			**Sipi mixed agriculture**		**Kawacom coffee factory**		
Water quality	Units	Inside forest	End of forest	Average	Inside forest	End of forest	Average	Inside mixed agriculture	Average	Kabiriro before factory	Kabiriro after factory	Average
Temp	^{o}C	17.5	19.2	18.4	17.7	16.5	17.1	16.1	16.3	21.8	21.6	21.7
Ec	µS/cm	63.4	67.1	65.3	65.5	71.9	68.7	41.5	56.7	148	188	168
TDS	Ppm	34.3	38	36.2	26.9	24.6	25.8	20.3	22.5	79.8	89.8	84.8
D.O	Ppm	11.1	9.7	10.4	9.8	9.3	9.6	11	10.2	8.5	9.8	9.2
pH		7.5	7.9	7.7	10.4	7.6	9	8.3	8	7.9	6	7
TURB	NTUs	11.7	13.1	12.4	24.9	26.6	25.8	4.1	15.4	73.1	54.2	63.7
TRANSP	Cm	25.8	35.3	30.6	42.4	5.7	47.1	63.8	57.8	25	32.7	28.9
SAL	Mg/l	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2
BOD	Ppm	4.4	5.3	4.9	3.9	4.6	4.3	3.6	4.1	4.5	6.4	5.5
TSS	Mg/l	1.3	2.3	1.8	2.1	1.1	1.6	0.2	0.7	0.04	0.54	2.9
NIT	Mg/l	1	1.8	1.4	1.8	1.3	1.6	1.3	1.3	0	2.8	1.4
PHOS	Mg/l	0	1.8	0.9	0	2.3	1.2	1.3	1.8	0	3	1.5
E. COLI	Cfu/100ml	50	30	40	50	380	220	180	280	0	0	0

It is only in the upper reaches where temperatures fell between 16.1-19.2^{o}C and in these reaches, the temperature was lowest at mid mixed agriculture (16.1^{o}C) and the highest was recorded at Kabiriro coffee factory zone with 21.8^{o}C.*E-coli* was only recorded in the natural forest and mixed agriculture in this reach with the highest number of 280 cfu/100ml found in the mixed farm land and 220cfu/100ml found in the Sipi end of forest. Generally, limno-chemical water quality was environmentally friendly in this reach. EC was highest at Kabirirocoffee factory zone with 168 µS/cm and was lowest at Sipi mixed farm (grazing grassland zone). Although, Kabiriro coffee factory zone had the highest concentration of turbidity, TDS, B.O.D and TSS, it is the only one that did not register any feacal coliform (*E-coli*) and had the least water transparency and pH. Nitrates and phosphates were higher in the mixed farms and coffee factory zones respectively. While turbidity was lowest in the natural forest with only 12.4NTUs at Chebonet, Salinity tended to be uniform ranging between 0.1-0.2mg/l.Chebonet natural forest had the highest amount of dissolved oxygen with10.4ppm and the lowest was at Kabiriro with9.2ppm. Generally, D.O was higher in this reach than middle and lower reaches.The potential sites of before natural forest,end ofSipi grazing land and mid coffee factory zones were not accessible and so not considered during the study.

Considering the sub-catchment (land use) level, as the water left the natural forest of Sipi, it had 0mg/l of phosphate and 50 cfu/100ml of *E.coli*, but by the time it reached mid of the mixed farm land which was the exact neighboringland use, these parameters had increased to 2.3mg/l and 380cfu/100ml respectively, B.O.D increased from3.9-4.6ppm, transparency increased from42-51cm, D.O reduced from9.8-9.3ppm and TDS reduced from26.9 to 24.6NTUs.In the same way, as the River Kabirirowater was entering the coffee factory zone, there was no phosphate and nitrate, but at the site just below thecoffee factory, the water had gained 3mg/l of phosphates and 2.8mg/l of nitrates. Apart from temperature and salinity, the rest of the parameters we measured before the factory zone had their values increased at the end of the factory zone. pH had reduced from 7.9 – 6 indicating the impact of waste effluent from the factory tending it towards acidity. The factory uses the stream as a dumping site for their effluent that connects to the bigger river Chebonet with the evidence of channels leading from the factory to the river.

4.3 Spatio-temporal water quality changes in the middle reaches of the Sironko catchment area:

Data about the physico-chemical water quality level in the middle reaches was recorded and summarized in table 3below:

Table 3 : Average values for both wet and dry seasons at sites in the middle reaches

		Makuyu urban				Makuyu planted forest				Budadiri sand mining			
Water quality	Units	B4 urban	Inside urban	End of urban	Average	B4 forest	Inside forest	End of forest	Average	B4 sand	In sand mining	End of sand	Average
Temp	^{o}C	20.8	21.5	21.6	21.3	21.6	19.4	20.2	20.4	20.9	21.1	20.7	20.9
Ec	µS/cm	256.5	269.3	162.5	229.4	162.5	144.5	133.3	146.8	120	136	121.8	125.9
TDS	Ppm	136	140.8	84.5	120.4	84.4	77.8	73.3	78.5	133.3	108	124.5	121.9
D.O	Ppm	10.1	8.7	9.6	9.5	9.6	13.6	10.8	11.7	8.4	8.2	8.3	8.3
Ph		8.6	8.6	7.8	8.3	7.8	6.9	8.4	7.7	7.4	8.2	7.6	7.7
TURB	NTUs	29.6	33	99.3	54	99.3	81.3	80.6	87.1	109.3	141.8	117.3	122.8
TRANSP	Cm	54.6	38.6	31	41.4	31	42	46	39.7	25.5	30.5	32	29.3
SAL	Mg/l	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
BOD	Ppm	5.6	8	7.1	6.9	7.8	7.8	6.8	7.2	4.9	4.9	4.9	4.9
TSS	Mg/l	0.2	0.7	0.3	0.4	0.3	0.3	0.3	0.3	0.6	14.1	0.4	5
NIT	Mg/l	0	1.5	3	1.5	3	4.3	6.6	4.6	5.3	1	2	2.8
PHOS	Mg/l	1.3	2	2.3	1.9	2.3	0.5	3	1.9	2	0	1.5	1.1
E. COLI	Cfu/100ml	0	100	200	100	200	0	0	0	0	0	0	0

The coolest temperature in the middle reaches of the mainstem river Sironko was 20.4^{o}C in the planted forest at Makuyu and highest was recorded at Makuyu urban centre with 21.3^{o}C. Just like the upper reaches, D.O was highest in the planted forest with 11.7. Urban centre had an EC of 229 µS/cm which was almost double the lowest value of 125ppmat Budadiri sand mining site. Much as the pH remained at 7.7 in both the forest and sand mining, turbidity of 122.8NTUs in the sand mining was by far more than in the forest and urban centre sites that had 87.1NTUs and 54NTUs respectively. Water transparency kept on reducing as the water moved downstream right from the urban centre where it was 41.4 cm to the forest which is the immediate nextland use where it was at 39.7cm and finally to where the sand mining reduced it to 29.3cm. The TSS of 0.4mg/l from Makuyu urban centre was only intercepted by the forest that reduced it to 0.3mg/l but later was escalated by sand mining to 5mg/l. In this reach it is only the urban centre that registered fecal coliform (*E-coli*) of 100cfu/100ml on average that was reduced before reaching the middle of the forest. The highest amount of nitrates was recorded in the forest with 4.6mg/l, a value that proved to be the highest in the whole catchment area (all the reaches). By the time this nitrate reached the sand mining area, it had reduced to 2.8mg/l. Phosphates in the two neighboring sites of urban centre and planted forest remained constant at 1.9mg/l but reduced at the sand mining site by 0.8mg/l.

Based on the sub-catchment scale, before the water entered the Makuyu urban centre, it had 0 cfu/100ml of fecal coliform (*E-coli*), by the time it reached middle of the urban centre, it had gained 100cfu/100ml and by the time it left the urban centre, fecal coliform had increased to 200cfu/100ml but as the water entered the planted forest and reached the middle of forest, the coliform had already been filtered out and so no coliform was recorded in the middle and end of the planted forest. Nitrates and phosphates loads were less before water entered the urban centre both at 0mg/l and 1.3mg/l respectively, which increased and by the time water was leaving town they had become 3 and 2.3mg/l. The nitrates increased progressively to the forest where it increased from 4.3 at the start of the forest to 6.6mg/l at the end of the forest,the highest value in the whole sub-catchment. The D.O of water at the start of the forest was at 9.6ppm, by middle of the forest it was reading 14.6ppm while at the end of forest it was 10.8ppm, the transparency of water at the start of the forest was 31cm, by the middle, it had increased to 42cm and by the end of the forest it was 46cm while TSS at the start of the sand mining was as low as 0.6mg/l, middle of the sand mining shot it to 14.1mg/l which receded to 0.4mg/l at the site just below the sand mining in Budadiri.

4.4Spatio-temporal water quality changes in the lower reaches of the Sironko catchment area:
Data about the Physico-chemical water quality level in the lower reaches was recorded and summarized in table 4below:

Table 4 : Average values for both wet and dry seasons at sites in the lower reaches

		Banana plantation				Nabbongurbanisation				Muyembe sugarcane plantation			
Water quality	Units	B4 banana	Inside banana	End of banana	Average	Before urban	Inside urban	End of urban	Average	B4 sugarcane	Inside sugarcane	Average	
Temp	^{o}C	22.9	22.3	24.4	23.2	24.4	24.5	24.7	24.5	21.6	21.7	21.7	
Ec	µS/cm	207	285.7	222.8	238.5	222.8	327.7	294.3	281.6	156.4	174.6	165.5	
TDS	Ppm	101	123.4	123	115.8	123	158.5	77.6	119.7	72.4	69.5	71	
D.O	Ppm	7.9	8.6	10	8.7	10	8.7	9.6	9.4	7.8	8.3	8.1	
Ph		8.3	7.8	7.9	8	7.9	7.7	7.9	7.8	6.4	7	6.7	
TURB	NTUs	240.8	147.5	171.8	186.7	171.8	194	181.5	182.2	66.7	44.8	55.8	
TRANP	Cm	22	21.3	18.3	20.5	18.3	20.6	17.8	18.9	30.6	34.5	32.6	
SAL	Mg/l	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	
BOD	Ppm	3.4	4.3	5.1	4.3	5.1	4.4	4.3	4.6	4.8	4.2	4.5	
TSS	Mg/l	4	3.6	0.4	2.6	0.4	0.5	3.4	1.4	0.2	0.2	0.2	
NIT	Mg/l	0.5	0	0	0.5	0	3.5	3	2.2	3.8	6	4.9	
PHOS	Mg/l	0.5	0	0	0.3	0	1.8	1.5	1.1	2.5	4.5	3.5	
E.COLI	Cfu/100mls	0	0	0	0	0	480	200	230	0	0	0	

Temperature in the lower reaches was hotter than the rest of the catchment reaches with ranges of between24.5^{o}C at Nabongo urban to 21.7^{o}C in the sugarcane plantation. Much as the banana plantation registered the highest EC of 238.5 µS/cm ahead of sugarcane that had the lowest Ec of165.5, it was not associated with any fecal coliform (*E-coli*) instead the urban centre was the only one that was contaminated with fecal coliform of 230cfu/100ml. Banana and sugarcane plantations produced the same amount of salinity of 0.1mg/l while the urban activities influenced a salinity of 0.2mg/l. sugarcane plantation was associated with highest nutrient loads of nitrate and phosphates followed by the urban influence with banana registering the lowest amount. The highest transparency was recorded in the sugarcane plantation with 32.6cm and the lowest transparency was recorded at the urban centre. Despite having the highest turbidity values of all lower reach land uses, banana plantation had the lowest B.O.D of 4.3ppm in this reach compared to the urban that had 4.6ppm and 4.5ppm of sugarcane plantation. Sugarcane plantation did not only have the lowest value of TDS at 71ppm but also had the lowest pH of 6.7 compared to urban that had pH of 7.8 and 8 for banana plantation.

Based on the sub-catchment scale, at the start of the banana plantation, the D.O was 7.9ppm which increased as the water traversed through the land use and by the time it came out of this land use it had increased to 10ppm which was also the starting point of urbanland use but by the time it came out of the urban, it had reduced to 9.6ppm. Turbidity levels at the start of banana were 240.8NTU, but by the middle of banana, it had reduced to 147.5NTU but BOD had increased from 3.4ppm to 5.1ppm. All the nutrients that came from land uses earlier than banana plantation, endedin the banana plantation. The activities had no impact on pH as it remained the same amount from the start to the end of the land use. Fecal coliform increased from 0 at the start of the urban to 480 cfu at the end of urban centre hence the highest number in the whole catchment. Nitrates also increased from 3 to 3.8mg/l unlike phosphates that reduced from 1.8 to 1.1mg/l. Sugarcane increased phosphates from 2.5 to 4.5mg/l and nitrates increased from 3.8 to 6mg/l but maintained the amount of TSS and SAL constant. Transparency increased and turbidity reduced for sugarcane plantation. TDS reduced but D.O increased for the sugarcane.

4.5 Relationship between land use size, local factors and water quality in Sironko catchment area:

In order to determine the relation between land use, local factors and water quality parameters across the different sites, Pearson correlation coefficient were generated from STATA Version.14 and results were summarized in table 5.

Table 5: Relationship between land use size, local factors and water quality in Sironko catchment area:

					Upper reaches								
	Temp	**Ec**	**TDS**	**D.O**	**pH**	**Turb**	**Transp**	**sal**	**BOD**	**TSS**	**Nitrates**	**phosph**	***E-coli***
land use size	-0.053	-0.3467	-0.195	0.4228	-0.0544	-0.3275	0.0232	0.305	0.0991	0.5816	-0.0034	-0.233	0
	0.901	**0.4001**	**0.6436**	**0.2966**	**0.8983**	**0.4285**	**0.9565**	**0.4626**	**0.8155**	**0.1305**	**0.9936**	**0.5787**	**0.4334**
Discharge	-0.75	-0.8345	-0.7864	0.5817	0.1691	-0.2312	0.1345	-0.1744	-0.4255	0.3433	-0.0567	-0.0074	0.3799
	0.032*	**0.01***	**0.0206***	**0.1304**	**0.6889**	**0.5817**	**0.7509**	**0.6795**	**0.2932**	**0.4051**	**0.8939**	**0.9861**	**0.3532**
Altitude	-0.806	-0.9237	-0.9034	0.4985	0.4317	0.0734	0.0138	-0.2241	-0.4705	0.6874	0.0143	-0.1388	0.3669
	0.016*	**0.001***	**0.0021***	**0.2086**	**0.2855**	**0.8629**	**0.9742**	**0.5937**	**0.2394**	**0.0596**	**0.9732**	**0.7431**	**0.3713**
					middle reaches								
Land use size	-0.457	-0.1873	-0.7781	0.7423	-0.2382	.	0.2908	-0.3053	0.6474	-0.3099	0.5566	0.2544	0.1468
	0.217	**0.6295**	**0.0135***	**0.022***	**0.5372**	**.**	**0.4477**	**0.4243**	**0.0595**	**0.4171**	**0.1196**	**0.5088**	**0.7063**
Discharge	0.443	0.83	0.3531	-0.0839	0.5324	.	0.383	0.7557	0.2855	-0.2584	-0.5081	0.1764	0.3856
	0.232	**0.0056***	**0.3513**	**0.8301**	**0.14**	**.**	**0.309**	**0.0185***	**0.4564**	**0.5021**	**0.1625**	**0.6499**	**0.3054**
Altitude	-0.145	0.4096	-0.5382	0.6965	0.1423	.	0.5737	0.2354	0.8669	-0.503	0.2001	0.3871	0.4287
	0.71	**0.2736**	**0.135**	**0.0371***	**0.7149**	**.**	**0.1062**	**0.5421**	**0.0025***	**0.1675**	**0.6057**	**0.3033**	**0.2495**
					lower reaches								
Land use size	0.137	0.21	0.3967	0.1204	0.6877	.	-0.518	-0.2988	-0.2478	0.5696	-0.7942	-0.7438	-0.2698
	0.746	**0.6177**	**0.3305**	**0.7764**	**0.0594**	**.**	**0.1885**	**0.4723**	**0.554**	**0.1405**	**0.0186***	**0.0344***	**0.5181**
Discharge	-0.579	-0.5786	-0.6331	-0.4303	-0.9139	.	0.8645	-0.1	0.1417	-0.5743	0.8454	0.8785	-0.0903
	0.133	**0.1329**	**0.092**	**0.2872**	**0.0015***	**.**	**0.0056***	**0.8137**	**0.7379**	**0.1365**	**0.0082***	**0.0041***	**0.8315**
Altitude	-0.384	-0.2564	0.0114	-0.2532	0.2176	.	0.0259	-0.6302	-0.2806	0.3771	-0.4777	-0.3538	-0.5691
	0.347	**0.5399**	**0.9786**	**0.5451**	**0.6048**	**.**	**0.9514**	**0.094**	**0.5008**	**0.3571**	**0.2313**	**0.3899**	**0.1409**

NB: bolded values are P- values,unbolded are coefficients while bolded with a symbol of a star are P<±0.05 (significant relationship)

From table 4, in the upper reaches, land use size had a negative correlation with temperature, Ec, TDS,pH, Turbidity, nitrate, phosphates and *E-coli* but with no significant relationship i.e all the P>0.05. This means that bigger land use sizes were associated with better water quality apart from salinity, TSS and BOD that increased in bigger land uses like forest due to the decay in the leaves from the forest trees and shrubs. The correlations in this reach showed that other local factors like altitude and discharge had a significant negative influence on water quality. For example; increase in discharge reduced temperature, Ec and TDS and these had respective P-values of 0.0322, 0.01 and 0.0206 while increase in altitude reduced temperature, Ec,and TDS with P-Values0.0157,0.001 and 0.0021 respectively.

In the middle reachesland use size negatively correlated with TDS and this relationship was significant at 5% level where the P-value registered was 0.0135. However this same land use and its size registered a significant positive relationship with D.O at a p-value of 0.022 and a coefficient value of 0.7423. Increase in discharge in this reach increased Ec at a P-value of 0.0056 and a coefficient of 0.83. The same amount of discharge was associated with increase in salinity with P-value of 0.0185 and coefficient of 0.7557. Increase in altitude on the other hand did not only lead to increase in D.O with a P-value of 0.0371 at a coefficient of 0.6965 but also increased BOD at a P-value of 0.0025 and a coefficient of 0.8669.

In the lower reaches, land use size had a significant negative relationship with nutrients. Large size of land use was associated with reduced concentration of nitrate loads as shown by a P-value of 0.0186 and coefficient of -0.7942 while the same land use size led to reduction in Phosphates at a P-value of 0.0344 and coefficient of -0.7438. Increase in discharge reduced pH at P- value of 0.0015 and a coefficient of -0.9139.

Increase in discharge on the otherhand came with increase in nutrients of nitrates and phosphates with p-Values of 0.0082, 0.0041 and coefficients of 0.8454, 0.8785 respectively.

V. Discussion

Upper reaches

The lowest temperature recorded at the upper reaches follows the natural environmental lapse rate theory of the higher you go the cooler it becomes which was as a result of higher altitude.

This study is in consonance with Niels *et al.*,(2016) who found out that fecal coliform remained higher in upper reaches of R. Awetu and Kito, the upper reaches of Sipi recoded higher *E-coli*, but the record of higher *E-coli* in the forest andmixed farm land of Sipi here was attributed to the wild animals that are found in the national park (protected forest reserve) like monkeys. Also the protected area is neighbored by a grazing ground and there was evidence of dung of domestic animals like cows and goats at the banks of River Sipi which when it rained would be washed into the river leading to the fecal contamination that we recorded

The study revealed an increase in EC, TDS, Turbidity and TSS that were recorded at the downstream of the coffee factory which is in agreement with what Raburu*et al.*,(2002) stated when he indicated thatall the water quality parameters measured below the sugarcane factory were poorer than above the factory. This poverty of water quality in this study was obviously as a result of untreated effluent from the coffee factory where even husks were observed floating in addition to the stench found on the site.

The higher nutrient loads of nitrates recorded at sites in the mixed agricultural area might be resulting from the compost manure of the cow dung. The dense vegetation cover and the limited disturbance of the natural forest at sites of Sipi and Chebonet forest account for the limited turbidity since these limit erosion of banks but only filtrates the water. This is similar to what Shivoga*et al.*, (2007) noted, by indicating that more nitrate comes from grazed grasslands and manured crops

Salinity at most sites tended to be uniform due to the homogeneity of the soils and bed rocks along the river profile which were volcanic. The general high record of D.O in the upper reach was associated with the high altitude and lower temperatures as well as the dense vegetation cover which is the major source of oxygen.

The increase in the water transparency from the natural forest to the grazing land is not different from the transparency that Kasangaki*et al.*,(2008) found in higher altitude of Bwindi only that, the one in this study was as a result of more filtration by the pasture than the forest. The water draining from the pasture was filtered hence the water appeared clearer than in the forest. At this same point the reduction in the D.O was because the mixed agricultural land is more open than in the forest where oxygen from dense tree cover was more.

The nutrient loads at the coffee factory were resulting from the decomposing raw wastes like husks and the detergents from the cleaning points in the factory. This might be the same reason for the decreasing pH that tended towards acidic like it was for Raburu*et al's.*,(2002) finding about sugarcane factory and water quality in Kenya.

Middle reaches

We found out thatPlanted forest at Makuyu just like in the upper reaches exhibited the lowest water temperatures and a higher D.O because of plentiful source of oxygen- the trees and shade provided by the trees.

The association of Makuyu urban centre with higher amounts of EC is attributed to the impervious surface leading to higher erosion and runoff that deposits different loads into the river during bankful discharge that raises the EC. This finding disagrees with the one of Raburu*et al.*, (2002) who found this situation in the reference sites that had little or no disturbance.

Van Butsel*et al.*, (2017) in his study found out that, large river sediment extraction has a large influence on river's Physico-chemical quality especially TSS and nutrients, a finding that has agreed with our study wherethe high turbidity in the sand mining was mainly as a result of humans disturbing the water by dislodging the boulders and sand from the rivers bed and banks causing higher TSS levels since sand and other lighter particles and some boulders were not allowed to settle in the river. This was especially at the end of the rainy season when the sand mining was at its peak.

The reduction in the transparency of the water from urban to forest and finally to sand mining was as a result of increase in the width of the channel leading to reduction in the depth of the channel hence reduction in the secchi depth.

Just like Niels *et al.*,(2016) indicated that Fecal coliform increased downstream of Awetu, we also found a similar case with Makuyu town where E-coli increased downstream the urban centre. The fecal coliform (E-coli) increment in the Makuyu urban center was attributed to the seepage of fecal materials from three latrines that are located at the bank of the river. There is alsoa possibility that people dispose fecal material into the river system and possibly somehow gets stuck in the river's stones in current with the containers like polythene bags used to dispose the material.

Higher nitrates were found in the Makuyu forest, a finding that differed from the one of Shivoga*et al.*,(2007). The higher nitrates loads in the planted forest is attributed to the rotting tree leaves and logs while the phosphate loads in the urban centre are attributed to the runoff from washing detergents from the populations.

Lower reaches:

Lower Ec in the sugarcane zone was due to gentle slope and intact riparian cover provided by sugarcanes hence limited bank and bed erosion. Given the fact that at a young stage of planting the sugarcanes, manures are applied, and also the large amount of rotting leaves of sugarcane produce manure, this might be responsible for the highest amount of nutrients of Nitrates and phosphates which agrees with (onyando*et al.*,2013) for river Isiukhu–Kakamega, Kenya.

The higher amount of fecal contamination in the Nabongo urban was attributed to direct disposal of fecal material into the river. The only attempt by local council that has been put in place to overcome this, is warning signpost 'DO NOT URINATE/DEFICATE IN THE RIVER- FINE ugSHs 50000='. This alone shows what people do in the night when nobody is watching them. Also two toilets were observed at the river banks, this situation is similar to what (Niels *et al.,* 2016) found in Jimmacity streams of Ethiopia.

The higher transparency of water in the sugarcane zone than elsewhere in the reach was attributed to the ability of the sugarcane to provide a filtration capacity of the incoming runoff in a manner similar to the papyrus, thereby limiting erosion in the sub catchment hence clarity of the water.

VI. Conclusions

Despite its small size and higher altitudinal location, industrial land use (KAWACOM coffee factory) has the most negative significant effect on the water quality and so mitigation measures should start with re-directing the effluent away from the Kabiriro stream to a constructed and gazetted waste treatment lagoon. The study also confirmed that higher fecal coliform loads in the middle and lower reaches in urban areas are a result of careless disposal of feces into the river and latrines constructed along the river banks that lead to ground seepage and ends up in the river especially during the rainy season when the water table rises. This can be handled by administratively ensuring that all homesteads and business establishment in urban centres have latrines and the latrines have to be at least 10metres away from the river.Generally upper reaches have better water quality levels than middle and lower reaches.Water temperature was lowest in the upper reaches and more so in forested areas. Turbidity was highest at urban centres and sand mining

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