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Influence of Seasons on Selected Water Quality Parameters within the Aquatic Ecosystem in South Nyanza Sugarcane Zone

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Abstract:

Sugarcane farming is the main agricultural activity done on a large scale in South Nyanza zone of Western Kenya. Farmers apply high rates of nitrogenous fertilizers for maximum yields. High rates of fertilizer application impact negatively on water physicochemical parameters within such ecosystems. However, such an impact seems to be region specific depending on land topology, soil type and rainfall patterns. In this work, we demonstrate the influence of seasonal variation on various physicochemical parameters within South Nyanza sugarcane belt. The parameters monitored include temperature, pH, turbidity, conductivity, biological oxygen demand, Cl^-, F^-, Fe^{2+}, Zn^{2+}, and Cu^{2+}. The concentration of these parameters was monitored both in the dry and wet seasons. The experiment was laid down in a two factor completely randomized design with site as the main treatment and season as a sub factor. Analysis of variance was used to analyze the differences between trends within seasons at $P \leq 0.05$. Mean seasonal results for wet season was 23 ^oC, 6, 135 NTU, 155 uS/cm, 65 ppm, 354 ppb, 100 ppb, 12 µg/L, 7 µg/L, and 6 µg/L respectively. While dry season was 26 ^oC, 7, 51 NTU, 106 uS/cm, 45 ppm, 168 ppb, 19 ppb, 2 µg/L, 1 µg/L, and 1 µg/L respectively. Seasonal variation greatly influenced the concentrations of physicochemical parameters within the sugarcane zone. The wet season is characterized with high fertilizer rate application and therefore it could be responsible for such like changes.

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1. Introduction

Sugarcane farming activities in South Nyanza Sugarcane zone started in 1979. This cash crop is extensively grown in this region by private small and large scale farmers led by the South Nyanza Sugar Factory that manufactures mill white sugar. Most of the small scale farmers rent out their land to the company and to private large scale farmers; hence most of the small scale farms also adopt usage of nitrogenous fertilizers used in the company nucleus estates and other large scale farms for better cane yields [1, 2]. The fertilizers are used repeatedly in this zone with their magnitude increasing every year (Table 1) as more farms are set aside for sugarcane plantation [3].

Table 1

Several studies have documented adverse effects of continued use of fertilizers on the soil chemistry that include but not limited to reduced soil pH, increased heavy metal loads, increased electrical conductivity and biochemical oxygen demand [4, 5, 6]. Specifically, the adverse effects of increased fertilizer application have been documented to be triggered by reduced soil pH [4]. For instance, reduction of soil pH makes heavy metals in the soil to become more soluble, bioavailable and mobile [4] hence processes such as surface runoffs, leaching and soil erosions that are more evident in wet seasons ad aid in mobility of these physicochemical parameters to aquatic systems. In the mobility of heavy metals, it all starts with ionization of metals increasing at low pH thereby increasing their water solubility and mobility after which the hydronium (H^+) ions displace most other cations on negative surface charges. This reduces metal adsorption by cation exchange and organic complexation [5]. Besides, Duinker *et al* [7] noted that use of commercial fertilizers affects soil chemistry and specifically lowers soil pH thereby increasing heavy metal solubility.

In the sugar industry, it has been realized that discharges from the factories have been adverse ecological effects. The deterioration of surface and groundwater quality is reported to be a consequence of changing or dynamic farm management strategies [3]. Most studies have shown that soil acidification takes place under sugarcane principally due to the use of nitrogeneous fertilizers containing or producing NH_4^+ [3, 6]. All ammoniacal nitrogeneous fertilizers release protons when NH_4^+ is oxidized to NO_3^- by nitrifying micro-organisms. Soil pH also decreases due to crop uptake of K, Ca and Mg. Hydrogen will replace these cations on the soil exchange surface. Industrial processing of sugarcane for production of sugar is a source of pollution for aquatic systems as large amounts of by-products and wastes are generated in the mills. Deposition and subsequent increase in aquatic systems physical chemical parameters have been documented to cause adverse effects on aquatic systems. For instance, bioaccumulation and bio concentration of toxic heavy metal residues in aquatic environments can result in their transfer into food chains putting terrestrial consumers including humans and birds at risk [8, 9, 10]. Contaminated food webs can also cause health and economic disadvantages to people as contaminated commercial foods like fish become restricted or banned due to high metal burdens [8, 9]. It therefore becomes important to monitor and suggest possible mitigation measures that can help in controlling deposition and increase of these physical chemical parameters to aquatic systems for apart from affecting the aquatic life, they indirectly affect human life as well burdens [10]. Some International and national aquatic systems physicochemical parameters standard levels beyond which the systems become stressed have been shown in Table 2. It is thus necessary to assess the influence of seasons on water quality parameters along the sugar cane zone.

2. Materials and Methodology

2.1. Area of Study

The study area was South Nyanza Sugarcane Zone lying between 0°55'S, 34°33'E and 0°47'S, 34°25'E with an elevation of 1472 m. The factory draws its water from Sare River which has a number of tributaries. The factory effluent is discharged back to the same river downstream. The area generally experiences an equatorial type of climate. The annual temperatures range from a minimum of 15^{0}C to a maximum of 30^{0}C. Most of the rain is received during the long rain season which is from March to May while the short rains season is from September to November. During the rains the tributaries and canals may carry with them residues of fertilizers applied on the agricultural lands into Sare River. The choice of study area was based on the level of fertilizer application as well as on the location of the tributaries that feed Sare River whose water is used in Awendo Township and by the South Nyanza Sugar factory. The Company Nucleus Estates use fertilizers in virtually every plot as opposed to the individual farmer owned plots (Outgrowers) where fertilizer usage is insignificant as most farmers may not be able to afford the high cost of fertilizers.

Table 1: History of repeated nitrogenous fertilizer application (in bags of 50 kg each) in some plots from South Nyanza Sugar Nucleus Estate farms in Western Kenya (*Agronomy Section, South Nyanza Sugar Company. NA: Not Applied)*

	Plots													
	102A		201A		306C		415B		508A		627B		524B	
Size	6.56(ha)		5.02 (ha)		3.67 (ha)		1.70 (ha)		7.41 (ha)		3.69 (ha)		2.43 (ha)	
Year	DAP	Urea	DAP	Urea	DAP	Urea	DAP	Urea	DAP	Urea	DAP	Urea	DAP	Urea
2005/06	50	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	40	NA	NA
2006/07	50	NA	40	45	35	50	15	NA	52	40	12	NA	10	NA
2007/08	50	55	NA	NA	NA	NA	NA	NA	NA	50	8	15	12	15
2008/09	NA	NA	30	NA	15	NA	NA	NA	NA	NA	NA	10	18	NA
2009/10	NA	25	NA	NA	NA	NA	NA	10	33	NA	NA	15	NA	5
Sum	150	80	70	45	50	50	15	10	85	90	20	80	40	20

Table 2: International and national aquatic systems physicochemical water parameters (KEBS, 1996; WHO, 1989.)

Parameter	Domestic water standard	Aquatic life standard
Temperature ^{o}C	< 30	< 40
pH	6.5 – 8.5	5 – 9
Conductivity µS/cm	< 50	< 1000
Biochemical oxygen demand		
Turbidity (NTU)	< 5	-
Chlorine (mg/l)	250	600
Fluorine (mg/l)	1.5	5
Iron	-	-
Zinc (mg/l)	2.0	45
Cupper (mg/l)	0.2	50
Chromium (mg/l)	0.1	50
Lead (mg/l)	0.1	< 10
Cadmium (mg/l)	0.01	< 10

3. Experimental Design and Sampling

The experiment was laid down in a two factor completely randomized design with site as the main factor and season as sub factor. Sampling was done in October 2008 during the wet season and in January 2009 in dry season. The sampling was done over 12 sites along and within Sare River. These included Mulo: 0^{0}58'00.78''S, 34^{0}35'16.30''E, Elev. 1464 m; Ng'ur Nyoyo: 0^{0}57'54.82''S, 34^{o}35'05.20''E, Elev.1461 m ; Marienga: 0^{0}56'30.04''S, 34^{0}34'08.40''E, Elev. 1443 m; Sony/Rinya Bridge: 0^{0}54'07.44''S, 34^{0}32'23.48''E, Elev.1418 m; Adega: 0^{0}54'18.26''S, 34^{0}32'06.41''E, Elev. 1418 m; Awendo: 0^{0}54'17.16''S, 34^{0}31'57.57''E, Elev. 1414 m; Sony/Ranjira Bridge: 0^{0}53'55.16''S, 34^{0}31'23.18''E, Elev.1411 m; Kombogo: 0^{0}53'00.66''S, 34^{0}31'27.50''E, Elev. 1404 m; Adel: 0^{0}53'00.68''S, 34^{0}32'04.56''E, Elev. 1420 m; Ogada: 0^{0}50'34.38''S, 34^{0}29'42.61''E, Elev.1361 m; Kodhia: 0^{0}49'20.50''S, 34^{0}30'01.41''E, Elev. 1312 m; Riat: 0^{0}49'31.16''S, 34^{0}23'25.05''E, 1258 m. Ranen Hill (0^{0}51'00.03''S, 34^{0}33'59.97''E) at an elevation of 1482 m was chosen for control site for soil.

Four 500 ml of water samples were taken from each sampling site in glass bottles in each of the sampling sites per trip. The sampling was done in replicates. During sampling, a shallow point (approximately 2 m into the river and in the middle of the canal), river bank left and river bank right were pooled and treated as one sampling site whereby three samples were collected and taken as replicates with a fourth as back up. In each case the samples were taken at an interval of 10 m apart during each sampling trip.

3.1. Determination of Heavy Metals in Water

The procedure adopted by Mzimela *et al.* [11] for total metal extraction was followed. A water sample measuring 200 ml was filtered through a 1 µm cellulose acetate filter with mill pores into an acid-washed 500 ml Erlenmeyer flask. The samples were acidified to 1% (2 ml) with conc. nitric acid (AR), placed on a hot plate at 60^{o}C and allowed to evaporate to approximately 30 ml. The evaporated sample was 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. The extract was analyzed for Pb, Cu, Cr, Zn, and Fe using Shimadzu AA-6200 Atomic Absorption Spectrophotometer with their respective Hamatsu hollow cathode lamps. Wavelengths of 283.3 nm, 324.8 nm, 357.9 nm, 213.8 nm, and 243.3 nm were used to measure absorbances of Pb, Cu, Cr, Zn and Fe, respectively [12, 13]. Before analysis was done, the AAS machine was calibrated.

3.2. Measurement of pH, Temperature, Turbidity and Electrical Conductivity

Water pH and temperature were measured directly in the field using a pH meter (3071 Jenway) and a mercury thermometer, respectively. Turbidity and Electrical conductivity were measured insitu using a turbidity meter (Hanna instruments Hi 93703 microprocessor turbidity meter) and electrical conductivity meter (Konduktometer, CG 857) respectively.

3.3. Halide Determination

The water samples were collected in clean 100 mL transparent plastic bottles and stored at -15C before analysis was done. The halides concentration was determined using total ionic strength adjustment buffer. The calibration was done by standard solutions containing 0.01, 0.1, 1.0, 10.0 and 100.0 ppm diluted from a stock solution.

3.4. Biochemical Oxygen Demand Analysis

The method by Mzimela *et al* [11] was used where ten milliliters of 0.1N $KMnO_4$ (potassium permanganate), 50 ml of distilled water and 10 ml of (1:3) concentrated sulphuric acid were added to each of two 250 ml conical flasks. 10 ml of the water sample was added to one of the flasks while to the second flask 10 ml of distilled water was added, this forming the blank. The contents of each of the flasks were mixed well and allowed to stand for one hour after which 10 ml of 10% potassium iodide (KI) was added to each of the two flasks. The liberated Iodine was titrated against 0.1N sodium thiosulphate with starch indicator.

3.5. Statistical Analysis

The means and ranges of the data collected were determined in this study. Ms Excel was used for data manipulation while a two factor completely randomized design in the MSTAT-C was used to separate the means of the sites and seasons and generate the least significance differences at 95% Confidence level.

4. Results and Discussion

4.1. Seasonal Variation of Selected physicochemical Parameters along Sare River

The seasonal variation of the physicochemical parameters of the water samples are presented in Table 3. The temperature regimes of the water samples varied significantly (P≤0.05) and ranged from 22.57 °C to 24.1 °C during the wet season and 24.97 °C to 26.97 °C in dry season. The pH profile of the water samples varied significantly (P≤0.05) due to seasonal variations in all the sites and ranged from 5.83 at Ogada and Kodhia to 6.66 at Adel in wet season and 7.10 at Adega to 7.79 at Kodhia in dry season. The pH levels obtained were generally lower in wet season than in dry season. The lower pH could be attributed to enhanced ammonification and nitrification processes in wet season [1]. The turbidity profile of the water samples varied significantly (P≤0.05) amongst the sample locations and ranged from 98.46 NTU at Mulo to 241.4 NTU at Awendo in wet season and 35.93 NTU at Adega to 95.39 NTU at Riat in dry season. The recorded turbidities were higher in wet season and increased downstream in line with a report by Oliver, [1] indicating that this was due to surface runoffs. Electrical conductivity regimes of the water samples varied significantly (P ≤ 0.05) from 91.37 µS/cm at Riat to 451.67 µS/cm at Awendo during the wet season and 68.63 µS/cm at Kombogo to 258.33 µS/cm at Awendo in dry season. The conductivities recorded were much higher in wet season than the dry season. The increase in electrical conductivity in wet weather is in agreement with the previous studies [4] that ionic mobility is enhanced in wet season. The BOD of the water samples varied significantly (P≤0.05) from 35.9 mg/l in Riat to 85.67 mg/l in Kombogo during the wet season and 34.35 mg/l in Riat to 66.78 mg/l in Kombogo in dry season. The recorded BOD levels were higher in wet season possibly due to surface runoffs [14].

Table 3: Levels of physicochemical parameters of water from Sare River and canals

Item		Sites												
		Mulo	N/Nyoyo	Marienga	S/Rinya	Adega	Awendo	S/R Bridge	Kombogo	Adel	Ogada	Kodhia	Riat	Mean season
Temperature(^{0}C)	Wet season	22.57	22.9	23.07	23.13	23.23	23.13	23.63	23.8	23.87	23.77	24.1	24.1	23.44
	Dry season	24.97	25.53	26.03	26.03	26.13	26.5	26.37	26.8	26.97	26.97	26.9	26.97	26.35
	Mean Sites	23.77	24.22	24.55	24.58	24.68	24.82	25	25.3	25.42	25.37	25.5	25.53	
	LSD(P≤0.05)				0.35						0.35			0.82
	CV%				1.1									
	Interaction				0.49									
pH	Wet season	6.37	6.15	6.42	6.47	5.9	6.24	6.23	6.2	6.66	5.83	5.83	6.27	6.22
	Dry season	7.51	7.14	7.44	7.48	7.1	7.37	7.67	7.59	7.3	7.11	7.79	7.72	7.44
	Mean Sites	6.94	6.65	6.93	6.98	6.5	6.81	6.95	6.89	6.98	6.47	6.81	7	
	LSD(P≤0.05)				0.41						0.41			0.97
	CV%				4.76									
	Interaction				0.58									
Turbidity(NTU)	Wet season	98.46	132.06	130.25	113.67	120.31	241.4	125.22	151.31	113.54	121.3	117.47	159	135.33
	Dry season	39.89	39.13	41.78	38.57	35.93	53.93	83.25	66.47	36.44	40.83	41.42	95.39	51.09
	Mean Sites	69.18	85.59	86.01	76.13	78.12	147.67	104.24	108.89	74.99	81.07	79.44	127.2	
	LSD(P≤0.05)				5.72						5.72			13.48
	CV%				4.83									
	Interaction				8.09									
E.Conductivity(uS/cm)	Wet season	100.6	224.33	120.3	81.87	85.65	451.67	129.27	143.11	120	177.4	133.83	91.37	154.95
	Dry season	91.07	101.37	103.4	73.6	77.87	258.33	84.2	68.63	101.8	139.4	96.47	74.73	105.91
	Mean Sites	95.83	162.85	111.85	77.73	81.76	355	106.73	105.87	110.9	158.4	115.15	83.05	
	LSD(P≤0.05)				8.83									20.81
	CV%				5.33									
	Interaction				12.49						12.49			
BOD(ppm)	Wet season	64.17	69.18	66.37	63.26	66.69	73.13	69.74	85.67	58.57	65.96	55.27	35.9	64.49
	Dry season	42.8	45.32	45.09	39.44	40.7	49.41	48.28	66.78	42.28	43.74	43.21	34.35	45.12
	Mean Sites	53.49	57.25	55.73	51.35	53.7	61.27	59.01	76.22	50.42	54.85	49.24	35.12	
	LSD(P≤0.05)				5.85						5.85			13.8
	CV%				8.41									
	Interaction				8.28							.		

4.2. Seasonal Variation in the Levels of Cl- and F-

The seasonal variation of the Cl^- and F^- concentrations of the water samples are presented in Table 4. The Cl^- concentration of the water samples varied significantly (P≤0.05) from 216 ppb at Kodhia to 750 ppb at Awendo during the wet season and 83.33 ppb at Ogada to 400 ppb at Awendo in dry season showing a general decline during the dry season. The F^- concentration of the water samples varied significantly (P≤0.05) from 55 ppb at Ng'ur Nyoyo to 211.67 ppb at Awendo in wet season and 13.67 ppb at Sony-Rinya Bridge, Marienga to 27.67 ppb at Kombogo similarly indicating a decline during the dry season. In both seasons, water samples from Awendo registered the highest concentration levels of Cl^- and F^- suggesting the location to be a major contamination point source. The Cl^- levels were much higher than the F^- concentrations in both seasons.

Table 4: Levels of Cl- and F- in water from Sare River (ppb)

Item		Sites												
		Mulo	**N/Nyoyo**	**Marienga**	**S/Rinya**	**Adega**	**Awendo**	**S/R Bridge**	**Kombogo**	**Adel**	**Ogada**	**Kodhia**	**Riat**	**Mean Season**
Cl^-	Wet Season	400	366.67	400	300	350	750	283.33	300	266.67	300	216.67	316.67	354.17
	Dry Season	150	116.67	150	150	133.33	400	216.67	150	183.33	83.33	133.33	150	168.06
	Mean Sites	275	241.67	275	225	241.67	575	250	225	225	191.67	175	233.33	
	LSD(P≤0.05)				69.19						69.19			163.07
	CV%				20.85									
	Interaction				97.85									
F^-	Wet Season	101.67	55.00	68.33	66.67	71.67	211.67	113.33	100	75	163.33	103.33	71.67	100.14
	Dry Season	14.67	18.33	13.67	13.67	19	24.5	27.67	21	20	23.5	22.33	17.33	19.64
	Mean Sites	58.17	36.67	41	40.17	45.33	118.08	70.5	60.5	47.5	93.42	62.83	44.5	
	LSD (P≤0.05)				19.82						19.82			46.71
	CV%				26.04									
	Interaction				28.03									

4.3. Seasonal Variation of Selected Heavy Metals Along Sare River

The seasonal variation of Fe, Zn and Cu concentrations of the water samples are presented in Table 5. Fe, Zn, Cu, varied significantly (P ≤ 0.05) due to seasonal variations in all the locations. Fe concentration levels varied from 3.31µg/l at Ng'ur Nyoyo to 17.06 µg/l at Sony-Ranjira Bridge during the wet season and from 0.65 µg/l at Mulo to 2.46 µg/l at Adel during the dry season. Concentration levels of Zn in the water samples varied from 4.37 µg/l in Mulo to 8.3 µg/l in Ogada during the wet season and from 0.36 µg/l at Mulo to 1.51 µg/l at Ogada showing the two sites to be having the lowest and highest concentration levels respectively. Cu concentration levels in the water samples varied from 3.72 µg/l at Marienga to 6.89 at Riat in wet season and from 0.21 µg/l at Mulo to 1.49 µg/l at Ogada during the dry season. There was significant (P ≤ 0.05) interaction effect for all the heavy metals, indicating that the responses did not occur in a uniform pattern. The reason for the trend could be due to high leaching caused by enhanced metal ionization during the wet season and decline in the heavy metal levels during the dry season due to limited leaching activity [4]. The leaching activity is largely influenced by the pH which is a major determinant of heavy metal mobility from the application points [5].

Table 5: Heavy metals concentration levels in water from Sare River (µg/L) (NB: Pb, Cr and Cd were not detected in all the water samples)

Item		Sites												
		Mulo	**N/Nyoyo**	**Marienga**	**S/Rinya**	**Adega**	**Awendo**	**S/R Bridge**	**Kombogo**	**Adel**	**Ogada**	**Kodhia**	**Riat**	**Mean Season**
Fe	Wet Season	6.64	3.31	7.23	4.24	13.28	15.41	17.06	14.91	15.59	15.5	13.62	13.95	11.73
	Dry Season	0.65	1.21	1.18	1.18	1.67	1.98	2.15	2.31	2.46	2.34	2.18	2.18	1.79
	Mean Sites	3.64	2.26	4.2	2.71	7.48	8.7	9.61	8.61	9.03	8.92	7.9	8.06	
	LSD (P≤0.05)				0.86									2.03
	CV%				10.04									
	Interaction				1.22									
Zn	Wet Season	4.37	5.47	6.3	6.89	7.43	7.32	6.62	6.07	7.85	8.3	7.23	7.25	6.76
	Dry Season	0.36	0.57	0.67	0.67	0.86	1.05	1.13	1.45	0.88	1.51	1.33	1.22	0.97
	Mean Sites	2.36	3.02	3.49	3.78	4.14	4.18	3.88	3.76	4.36	4.91	4.28	4.23	
	LSD (P≤0.05)				0.34									0.81
	CV%				6.99									
	Interaction				0.49									
Cu	Wet Season	3.84	4.45	3.72	5.58	5.85	5.27	6.19	6.38	6.56	6.67	5.86	6.89	5.6
	Dry Season	0.21	0.66	0.44	0.44	0.73	0.95	0.95	1.15	1.09	1.49	1.17	1.64	0.91
	Mean Sites	2.02	2.55	2.08	3.01	3.29	3.11	3.57	3.76	3.82	4.08	3.51	4.27	
	LSD (P≤0.05)				0.4									0.94
	CV%				9.65									
	Interaction				0.56									

5. Conclusions

The heavy metal burden in the aquatic environment within South Nyanza Sugarcane farms were within allowable limits as shown by levels in water in River Sare and tributaries. Heavy metals are naturally occurring in South Nyanza Sugar belt as shown in the control site and the fertilizers used also contain these heavy metals as contaminants. Surface runoffs and erosion in the sugarcane farms may be responsible for transportation of heavy metals and nutrients from the farms into the aquatic systems thereby polluting the system through higher BOD and heavy metals in wet seasons. However, the concentrations of the heavy metals remain lower than the upper limits recommended by WHO and USEPA.

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