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Original Research Article

The extent of nutrient removal by wastewater treatment plants along the Nyalenda Wigwa Stream and the River Kisat (Kenya)

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ABSTRACT

Kisat Wastewater Treatment Plant (KWWTP) and Nyalenda Waste Stabilization Ponds (NWSP) clean wastewater before discharge into Winam Gulf (Lake Victoria), but there is lack of information on their efficiency. The current study was carried out to determine the efficiency of nitrogen and phosphorus removal from Kisumu City wastewater disposal by KWWTP and NWSP. Samples of water were collected from the inlet, within and outlet of the treatment plants, preserved, processed and analyzed using standard methods. The concentrations varied significantly ($P \leq 0.05$) between inlet, within and outlet at KWWTP and NWSP except for NH_3-N which had no significant difference. Percentages of nutrient removal at KWWTP were 41.3% NO_2^--N, 13.7% NO_3^--N, −5% NH_3-N, 27% N_{Org} and 10.4% (T-P); while at NWSP the levels were 50%, 10.4%, 0%, 16.6% and 30.8%, respectively. These percentage removals of nitrogen and phosphorus in both the treatment plants were below the internationally acceptable minimum values. Hence urgent mitigation steps are necessary to modernize KWWTP and possibly widen and deepen the NWSP to counter this problem.

1. Introduction

Anthropogenic activities such as the use of fertilizers in farming, industrial processes such as food processing and human sewage can lead to accumulation of the nutrients of nitrogen and phosphorus in the environment, even after effective treatment of organic wastes in wastewater treatment plants (UN, 2009). Past studies show ineffective or lack of proper effluent treatment in Kenya, therefore the concentrations of chemical nutrients discharged may be great (Nzomo, 2005). Kisat Wastewater Treatment Plant (KWTP) and (NWSP) are located along the River Kisat (RK) and Nyalenda Wigwa Stream (NWS), respectively. Odada *et al.* (2004) noted that these, as well as other, wastewater treatment plants malfunction; therefore are inefficient in removing nutrients. Efficient measures are necessary in order to ensure that chemicals and nutrients are removed. Nitrogen and phosphorus are believed to lead to the flourishing of water hyacinth, an alien invasive, in the Winam Gulf, which has impeded water transport and led to recorded death of aquatic animals as a result of the deoxygenation it causes (Nzomo, 2005; Agak, 2000; Mwita and Nkwengulila, 2008; Kayombo and Jorgensen, 2006).

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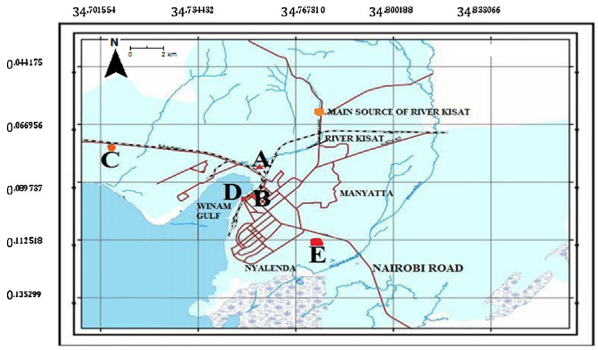

Fig. 1. Map of the Winam Gulf showing the location of Kisumu City, (A) Kisat Wastewater Treatment Plant and the fish processing factory, (B) flour mill, (C) matchbox factory, (D) landfill, (E) Nyalenda Waste Stabilization Ponds (modified from Butler, 1959).

Treating wastewater effectively to return it to the environment or for human use is one of the most important parts of the Ecohydrology paradigm, particularly using arterial wetlands, as stabilization ponds, to undertake this treatment.

2. Materials and methods

Samples were collected from the Kisat Wastewater Treatment Plant (KWWTP), the Nyalenda Waste Stabilization Ponds (NWSP) – lagoons, the Nyalenda Wigwa Stream (NWS) located near NWSP and the River Kisat (RK) located in Kisumu City, Kenya, as illustrated in Figs. 1, A and B.

The main source of River Kisat is 0°04′49.21″S, 34°45′36.33″E with an elevation of 1131.9 m above mean sea level, KWTP is 0°05′02.10″S, 34°45′15.10″E with an elevation of 1126.5 m while NWSP are 0°06′49.25″ S, 34°46′25.41″ E with an elevation of 1124.4 m above mean sea level. Filter tank 1 and filter tank 2 at KWTP are represented by 2c and 2d respectively (Fig. 2a). The numbers 4, 5, 6 and 7 represent main source of River Kisat, pre-junction FPF, post-junction FPF and post-junction KWWTP, respectively. Post-junction KWWTP is a sampling site after the convergent point between flowing discharge from Kisat Wastewater Treatment Plant and River Kisat. Lagoon 1 and Lagoon 2 are within NWSP and are represented by 2a and 2b, respectively (Fig. 2b). Numbers 4 and 5 represent pre-junction and post-junction sites, respectively. Pre-junction lagoons is a sampling site before the convergent point between runoffs from Nyalenda settlement and lagoons outlet. Post-junction lagoons is a sampling site after the convergent point between lagoons outlet and flowing Nyalenda Wigwa Stream.

Samples in triplicates were collected in a Completely Randomized Design (CRD) at three different times of the day, 8.00 am, 12.00 noon and 6.00 pm in the same day for three continuous days. 0.5 dm^3 of wastewater sample was collected at each time, using a dip container and poured into a glass bottle. The samples taken at each respective time were mixed to form a composite sample, preserved and stored until after the third day when collection of the composite sample was complete. Preservation and storage of samples was done according to the methods recom-

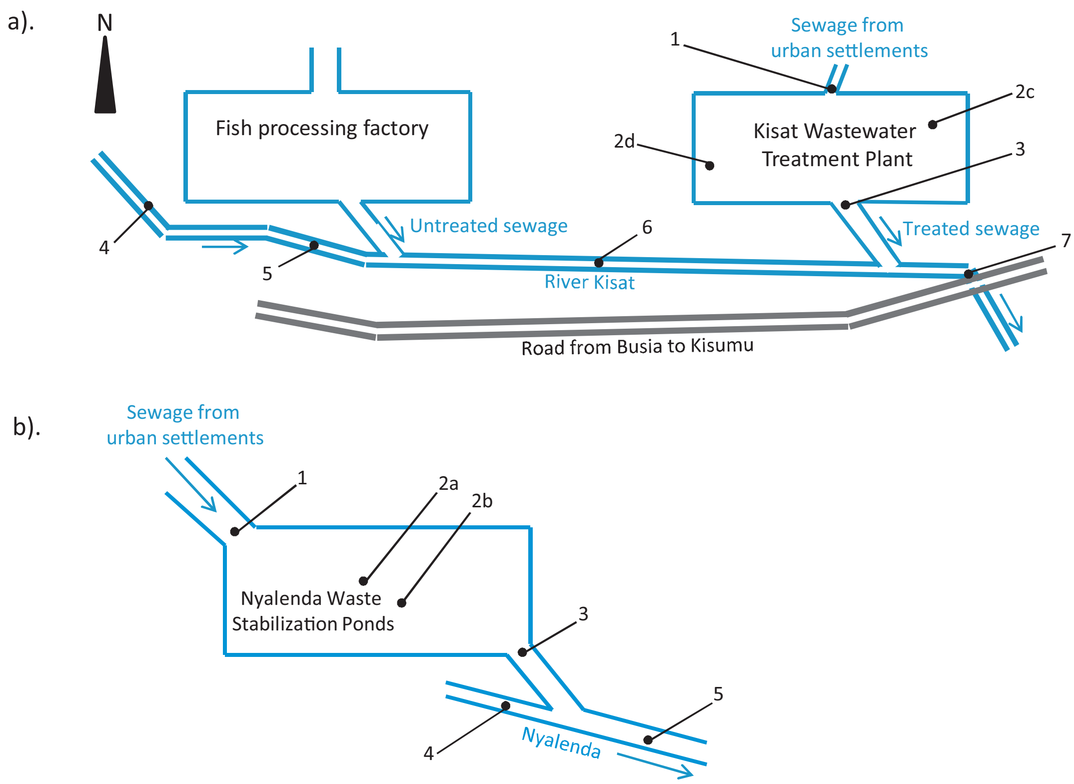

Fig. 2. (a) A schematic view of sampling sites at Kisat Wastewater Treatment Plant (KWWTP), fish processing factory (FPF) and River Kisat. (b) Schematic view of sampling sites at Nyalenda Waste Stabilization Ponds.

mended by Eaton *et al.* (1995). The samples were then transported and refrigerated for further storage prior to the analysis. The frozen samples were allowed to thaw to room temperature prior analysis.

Solvents, reagents and standards used in this study were of analytical grade (AR). Greiss-Ilosva diazotization with UV–Vis spectrophotometric method was used in the analysis of nitrite nitrogen (NO_2^--N). The experimental procedure and chemical analysis methods for determination of NO_2^--N by Greenberg *et al.* (1985) were adopted. Cadmium reduction method followed by Greiss-Ilosva diazotization with UV–Vis spectrophotometric method was used in the analysis of nitrate nitrogen (NO_3^--N). Kjeldahl distillation followed by back titration method was used in the analysis of ammonia nitrogen (NH_3-N) while Kjeldahl digestion followed by distillation and then back titration method was used in the analysis of organic nitrogen (N_{Org}-N). The experimental procedure by Greenberg *et al.* (1985) and Day and Underwood (1991) were adopted while analysis was done according to the method by Greenberg et al. (1985), using digestion followed by vanadomolybdophosphoric acid colorimetric measurement method used for total phosphorus (T-P). Standards with each set of samples were also analyzed using the method of Greenberg *et al.* (1985). The MSTAT-C programme of analysis of variance was run on all the analytical data collected.

3. Results

The concentrations of nutrient parameters at Kisat Wastewater Treatment Plant are presented in Table 1. There was significant ($P \leq 0.05$) reduction in concentration of each nutrient parameter between the inlet and outlet except for NH_3-N.

The concentrations of nutrient parameters at Nyalenda Waste Stabilization Ponds are presented in Table 2. There was significant ($P \leq 0.05$) decrease in the concentration of nutrient parameters as from the inlet to the outlet except for NH_3-N, as occurred with the Treatment Works. There was an increase in concentrations of NO_2^--N, NO_3^--N, NH_3^--N, N_{Org} and T-P along the Nyalenda Wigwa Stream, although not high (0.101 mg dm^{-3}, 0.470 mg dm^{-3}, 0.155 mg dm^{-3}, 0.534 mg dm^{-3} and 0.437 mg dm^{-3}, respectively).

The concentrations of nutrient parameters along River Kisat (RK) are presented in Table 3. There was significant increase in the concentration of nutrient parameters from the main source to the downstream of River Kisat.

Table 1
Variation of concentration (mg dm^{-3}) of nutrient parameters at Kisat Wastewater Treatment Plant.

Sampling sites	Concentration (mg dm^{-3})				
	NO_2^--N	NO_3^--N	NH_3-N	N_{Org}	T-P
Inlet	0.046	1.71	2.38	2.66	1.37
Filter 1	0.035	1.57	2.31	2.56	1.31
Filter 2	0.03	1.53	2.31	2.4	2.27
Outlet	0.027	1.48	2.5	1.94	1.23
CV%	5.66	0.77	0.13	0.04	1.55
LSD ($P \leq 0.05$)	0.005	0.032	0.008	0.003	0.052
Concentration of nutrient removed	0.019	0.235	−0.116	0.72	0.142
Percentage of nutrient removed	41.3	13.7	−4.9	27	10.4
Guideline allowable limits (mg dm^{-3})	3[a]	10[a]	0.5[b]	10[a]	1[c]

[a] WHO (2004).
[b] GOK (2006).
[c] Jiang et al. (2004), T-P: total phosphorus, LSD: least significant difference, CV%: coefficient of variation percentage

Table 2
Variation of concentration (mg dm^{-3}) for nutrient parameters at Nyalenda Waste Stabilization Ponds.

Sampling sites	Mean concentration (mg dm^{-3})				
	NO_2^--N	NO_3^--N	NH_3-N	N_{Org}	T-P
Inlet	0.146	1.81	2.15	2.66	1.54
Lagoon 1	0.119	1.72	2.33	2.52	1.54
Lagoon 2	0.118	1.65	2.4	2.27	1.49
Outlet	0.073	1.62	2.33	2.22	1.07
Pre-junction lagoons	0.017	1.35	2.33	2.07	0.53
Post-junction lagoons	0.118	1.82	2.48	2.61	0.967
CV%	15	0.79	19.8	0.03	2.11
LSV ($P \leq 0.05$)	0.031	0.028	NS	0.001	0.053
Concentration of nutrient removed	0.073	0.188	0	0.441	0.475
Percentage of nutrient removed	50	10.4	0.00	16.6	30.8
Guideline allowable limit (mg dm^{-3})	3[a]	10[a]	0.5[b]	10[a]	1[c]
Increase along the NWS	0.101	0.47	0.155	0.534	0.437

[a] WHO (2004).
[b] GOK (2006).
[c] Jiang et al. (2004), NS: not significant

Table 3
Variation of the concentration (mg dm^{-3}) of nutrient parameters at River Kisat (RK).

	NO_2^--N	NO_3^--N	NH_3-N	N_{Org}	T-P
Main source	0.011	1.39	1.31	1.49	0.856
Pre-junction FPF	0.02	1.69	2.37	2.54	0.651
Post-junction FPF	0.078	1.85	2.64	2.78	0.968
Post-junction KWWTP	0.177	2.1	2.78	2.95	1.17
CV%	4.05	0.38	0.25	0.1	0.86
LSD ($P \leq 0.05$)	0.008	0.017	0.015	0.006	0.02
Guideline allowable limit	3[a]	10[a]	0.5[b]	10[a]	1[c]
Increment along RK	0.166	0.711	1.47	1.46	0.315

[a] WHO (2004).
[b] GOK (2006).
[c] Jiang et al. (2004).

4. Discussion

The increase in NH_3-N through the works is due to reduction of N_{Org}, NO_2^--N and NO_3^--N by denitrification under anaerobic conditions (Sawyer, 2003). The concentration of T-P decrease could be due to uptake or adsorption by bottom/suspended sediments (Neal *et al.*, 2000). This was high because of the opposite reaction due to increased hydrological energy and its effects on the physical mechanisms of phosphorus release (Hanrahan *et al.*, 2003).

The concentrations of NH_3-N and T-P discharged are above the maximum guideline allowable limits of 0.500 mg dm^{-3} (GOK, 2006) and 1.000 mg dm^{-3} (Jiang *et al.*, 2004), respectively and this gives an indication that there is need for urgent mitigation measures to be put in place to restore normality. The discharge concentrations of NO_2^--N, NO_3^--N and N_{Org} are within guideline limits of 3.000 mg dm^{-3}, 10.000 mg dm^{-3} and 10.000 mg dm^{-3} (WHO, 2004), respectively (Table 1) and hence do not raise alarm. Nutrient parameters in the urban wastewater were drained through KWWTP into River Kisat, even though the amounts of most of the parameters were significantly reduced by the wastewater treatment process.

The percentage removal rates were also below guidelines, emphasizing the urgent need for intervention measures in form of modernizing the treatment plant to adhere to the set lowest guidelines.

This decrease achieved in the stabilization ponds was attributed to efficient utilization of nutrients by macrophytic vegetation. The lack of change in NH_3-N was attributed to nitrification and denitrification processes.

The significant increase in the concentration of other nutrients in the Nyalenda Wigwa Stream with passage downstream is a response to the discharge from the ponds, which are above guideline allowable limits of 0.500 mg dm^{-3} (GOK, 2006) and 1.000 mg dm^{-3} (Jiang *et al.*, 2004), respectively. The percentage concentration of NO_2^--N removed was well above the minimum guideline of 1.000% (Gloyna, 1971; Awuah and Abrokwa, 2008) hence the process of removal is acceptable for this nutrient. Percentage concentrations of nutrients removed for NO_3-N, NH_3-N, N_{Org} and T-P were below the lowest guidelines of 23.800%, 39.500%, 57.300% and 40.000%, respectively (Gloyna, 1971; Awuah and Abrokwa, 2008). This calls for more to be done in terms of widening and deepening of the stabilization ponds to allow longer time in stabilization which could effectively lead to increased reduction in nitrogen and total phosphorus nutrient removal. This lower state removal of the nutrients could be due to uncontrolled urban human population growth in Kisumu City, which therefore calls for wide mitigation measures to be put in place.

The River Kisat is clearly polluted by more than just the wastewater treatment and here the influences of diffuse sources including agricultural runoff into the river can be seen. Therefore the deposition of these nutrient parameters into River Kisat could be making Lake Victoria more contaminated due to the accumulation factor although the concentrations of the various points sampled agree with the maximum guideline allowable limits.

5. Conclusions

Kisat Wastewater Treatment Plant and Nyalenda Waste Stabilization Ponds are not efficient in removing nitrogen and phosphorus from wastewater as the percentage concentrations removed are below the international minimum guideline allowable limits. This calls for urgent modernization of the treatment plant. Also due to uncontrolled increase in human population in Kisumu City, there is need to widen and deepen the Nalenda Waste Stabilization Ponds. Alternatively more stabilization ponds could be established. These mitigation measures could lead to efficient removal or degradation of nutrients from wastewater and hence have water at the outlets of the treatment plants with acceptable levels of the concerned nutrients and the percentage removal of the nutrients could also be within the acceptable range.

Concentrations of the nutrient parameters increase from upstream to downstream of River Kisat and the same trend is observed along Nyalenda Wigwa Stream. This was attributed to possible pollution along the river and stream since a number of factories and the Kisumu City Council pours their wastes into these waters.

Conflict of interest

None declared.

Financial disclosure

None declared.

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