Wastewater Treatment in a Growing Municipality: Evaluating the Efficiency of the Suneka Plant in Kisii, Kenya

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Abstract

Wastewater stabilization ponds (WSPs) are widely used in the tropics for sewage wastewater treatment because they are inexpensive to operate. However, they have been associated as being point sources of pollution to the environment. The purpose of this study was to assess Suneka WSP's wastewater treatment efficiency. Sampling was done from May to August 2021. Dissolved oxygen (DO), pH, temperature, total dissolved solids (TDS) and electrical conductivity (EC) were measured in situ using YSI multi-parameter probe model 35C. Ex situ analyses of nutrients, total suspended solids (TSS), total and fecal coliforms (TC and FC), and chlorophyll-a were conducted in accordance with the standard protocols outlined in APHA, 2014. The effluent's levels of physical, chemical, and biological (coliform) parameters were compared to those set by the National Environment Management Authority (NEMA). The mean EC, DO, TDS, SRP, NO_3-N, NO_2-N, TN and TP differed significantly among the sampling sites (ANOVA; $p < 0.05$). The means of TC and FC were 37.64 ± 3.3 and 17.94 ± 2.3 counts/100ml. TDS, temperature, pH, and NO_3-N were within NEMA, WHO, and EPA standards while others were above, indicating that the plant did not efficiently polish the wastewater. Moreover, most of the assessed parameters including TP, TN and coliforms had polishing efficiency below 70% in addition to not meeting the required standards. As a result, the poor water quality and eutrophication of Riana River can be attributed to the two nutrients. To further polishing of the effluent from the WSP, this study recommends construction of a wetland

Keywords: Suneka Wastewater Treatment Plant, Wastewater Stabilization Ponds, Capacity, Wastewater, Pollution, Effluent, Wastewater Quality Standards

Introduction

Access to potable water to mankind on earth is an increasing concern due to its scarcity resulting from pollution of their natural sources (Atwebembeire *et al.,*2019; Rayori *et. al*., 2024). Further, climate change has negatively affected the rainfall patterns and intensity worsening the situation. Properly treated wastewater can serve as an alternative source of water for domestic, agricultural, and industrial purposes towards addressing the potable water scarcity (Darko, Azanu, & Logo, 2016; Unesco, 2017). Moreover, wastewater is readily available throughout the year and contains nutrients that can promote plant (macrophytes, and algae) (Omweno *et al.,*2024; Owino *et al.,*2020) and animal growth (zooplankton) (Rayori *et al.,*2023). In Asian countries, they have successfully used treated wastewater for aquaculture among other uses and the products have a ready market. On the other hand, in Africa, more so Kenya, products produced in this manner including those that sludge is used lacks ready market due to safety concerns arising from the quality of the treated sludge and wastewater used. Hence there is a lack of the ready markets for food crops and fish produced in this manner (Bannerji S., 2014; Kumar *et al.,*2014; Rayori D M., 2023; Sarah *et al.,*2024).

Unlike developed countries, developing countries have been characterized with discharge of partially or untreated wastewater into the environment, or for re-use. In the former countries, wastewater treatment facilities are conventional and automated unlike in the latter where they are non-conventional. Typical examples of conventional methods include: activated sludge, rotating biological contactor and trickling methods (Aregu M B., 2022; Douglas *et al.,*2022). Soil aquifers, constructed wetlands, oxidation ditches, and wastewater stabilizing ponds are among the non-conventional methods used in wastewater treatment (Rayori D M., 2023). Unlike the conventional methods, these methods are low-cost, less sophisticated, and low technology in maintenance and operation thus preferred in most developing countries more so in the Tropics (Amoatey & Bani, 2011).

In Kenya, there are more than 40 sewage treatment plants among them being waste stabilization ponds (WSPs) located in most of the large municipalities (Rayori *et al.,*2021; Sarah *et al.,*2024). These WSPs have been characterized with poor management and lack of capacity to handle huge volumes of wastewater thus discharging untreated or partially treated wastewater into the environment (Wanjohi, Mwasi, Mwamburi, & Isaboke, 2019). This is of great concern due to the potential hazards the wastewater poses to the environment, human and animals (Omondi A. & Merceline A., 2023; Rayori *et al.,*2024; UNESCO 2017). The hazards associated with wastewater include but are not limited to: excreta-related pathogens, toxic chemicals (Hart *et al.,*2025), heavy metals (Douglas *et al.,*2024; Morsy *et al.,*2020) skin irritants, and vectors that can transmit pathogens (Darko *et al.,*2016; Laffite *et al.,*2016). Nevertheless, communities living around these plants use the discharged effluent from the WSPs for aquaculture, domestic, industrial and agricultural purposes to produce more food so as to increase household food security and nutrition (Kilingo, Bernard, & Hong, 2021). This is undertaken oblivious of the various hazards associated with the reuse of treated or partially treated wastewater (Darko *et al.,*2016; Sarah *et al.,* 2024).

The mandate for collecting and treating sewerage wastewater in Kisii town, Kisii County and its environs is bestowed on the Gusii Water and Sewerage Company (Rayori D M., 2023). The population of Kisii municipality is ever increasing resulting in increasing amount of wastewater produced, which has overwhelmed the wastewater management systems in the Suneka WSP (Douglas *et al.*,2024; Douglas *et al*.,2022; Rayori *et al.*,2024). Consequently, the plant discharges partially treated wastewater into Riana river which eventually discharges into river Kuja, which empties its water into Lake Victoria. Also, it has been observed that during the rainy season, the sewer lines within the town tend to overflow and the raw sewage is spilled to the receiving waters and the environment. This renders the surface water unfit for use and environmental pollution that has resulted to public outcry (Rayori D M., 2023; Rayori *et al*., 2024). On the other hand, Kisii town residents are demanding for alternative sources of portable water for use. This necessitated the renovation and expansion of the Suneka WSP which serves the municipality and its environs (Rayori D M., 2023). Nevertheless, because the sewage distribution network is confined to a smaller area and a greater number of houses remain not connected to the sewage distribution network, the ability to handle the wastewater treatment of the Kisii Municipality remains insufficient. Most of the households either use septic tanks and latrines to manage their wastewater (Onderi Z. & Ongori M., 2019; Rayori D M., 2023).

Therefore, it is necessary to make sure that semi-treated wastewater is treated before being discharged into receiving waters in order to safeguard downstream consumers from its detrimental effects, given the possible hazards involved with its use (Douglas *et al*.,2022; Rayori D M., 2023; Rayori *et al*.,2024). The effectiveness of Suneka WSP's wastewater treatment process was assessed in this study.

Materials And Methods

Study Area

The current study was conducted at Suneka WSP which has a capacity of 15,000 m^3/day. The physical location of the WSP is in Suneka at latitude 00 39' 30'' S and longitude 340 42' 30'' E at Kisii county, Kenya Figure 1. The plant treats sewage water from Kisii town and its environs. To improve the plant's efficiency in wastewater treatment, it was recently renovated to its current capacity. The renovation of the plant was necessitated due to increased institutional, domestic, and agricultural wastewater resulting from an increased population within the municipality. The treated wastewater from the plant that's the effluent is discharged into Riana River a tributary of river Kuja which in turn empties its waters into Lake Victoria.

Figure 1: Study area map of the Suneka WSP.

Key: White line indicates river Riana;Wwhite stars indicate the sampling sites. Alphabet letters indicate I- influent, A-Anaerobic Pond, F- Facultative Pond, M1- Maturation Pond 1, T- Tertiary pond, E- effluent

Wastewater Sampling

During May through August of 2021 wastewater samples were collected once a month for analysis and the grab method was used to collect the wastewater samples. The samples were collected in triplicate in the morning hours between 8.00-10.00 am from the four identified sampling sites. The sites include: Influent (the raw sewage wastewater before entering the anaerobic pond), effluent prior to discharge into the river, and two locations within the river that are 100 meters upstream and downstream at the effluent discharge point into the River Riana Figure 1.

Three separate subsurface wastewater samples were collected for TSS and nutrient analyses in 500 ml polypropylene plastic bottles that had been previously cleaned and rinsed with double-distilled water. The filled bottles were immediately kept in a portable cooler boxer at 4°C then transported to the laboratory for analysis.

Physical Parameters Analysis

A calibrated portable professional series (YSI) multi-parameter meter model 35C was used to measure *in situ* parameters namely: dissolved oxygen concentrations (DO) (mgL^{-1}), pH, electrical conductivity (EC) (μScm^{-1}), temperature (°C), and total dissolved solids (TDS) (mgL^{-1}) levels at the sub-surface level. Deionized water was used to thoroughly rinse the probes after each measurement was taken. At each sampling site, the readings for each parameter were taken in triplicate.

The filter papers used to determine TSS levels were pre-weighed using analytical balance (Model: Shimadzu-ATX224) and the readings were recorded. The weighed filter papers were then put on the top of the filtration flask and screwed in the filtration cap. To start the filtration process, a 100 ml wastewater sample was placed in the filtration flask and the vacuum pump was turned on. Once the filtration process was complete, using forceps, the filter paper was gently taken out of the filtering equipment and placed on a glass weighing dish for support and dried in a drying oven for an hour at 110°C to a constant weight. Afterward, the dried filter paper was removed from the petridish and re-weighed using an analytical balance (Model: Shimadzu-ATX224) and the weight obtained was recorded.

The following formula was used to determine the TSS:

$$\mathrm{TSS}\left(\frac{\mathrm{mg}}{\mathrm{L}}\right) = \frac{(\mathrm{Residue+Filter})(\mathrm{mg}) - \mathrm{Filter}(\mathrm{mg})}{\mathrm{Sample\ filtered\ (mL)}} \times x\, 1000 \left(\frac{mL}{L}\right) \qquad \text{Equation 1}$$

Chemical Parameters Analysis

The chemical parameters that were analyzed include: silicates (SiO_2), soluble reactive phosphorous (SRP), nitrates (NO_3-N), nitrites (NO_2-N), ammonium (NH_4-N), total nitrogen (TN), and total phosphorous (TP). They were analyzed following the standard spectrophotometric method for the determination of water and wastewater as described in APHA, (2014).

Data Analyses

To organize the physical, chemical, and coliform data collected from the various sampling sites, Microsoft Excel version 2010 was utilized. To test significant differences, One-Way Analysis of Variance (ANOVA) was used to assess spatial variations in the physical, chemical, and coliform parameters at a predetermined alpha value of 0.05. To determine where the differences between the sampling sites were, *post hoc* analysis was conducted using the Tukey pairwise comparisons with SPSS version 22 where the mean variations were significant.

Percentage Reduction Efficiency

Efficiency in wastewater polishing for a treatment plant is assessed by measuring the reduction of pollutants consequently, the discharged effluent meeting the prescribed standards both locally, nationally, and internationally. In the current study, percentage reduction efficiency was calculated using the NEMA standards for effluent discharges into the environment.

To determine the effectiveness of the Suneka WSP in wastewater polishing, pollutant removal efficiency were calculated for physical and chemical parameters and coliforms using the equation below (Rayori *et al*., 2021):

$$Percentage\ reduction = \left(\frac{\text{Conc. of pollutant in influent} - \text{conc. of pollutant in effluent}}{\text{Conc. of influent}}\right) \times 10$$

Equation 2

However, during wastewater polishing some of the parameters like temperature, pH, and DO levels increase between the influent and effluent an indication of wastewater quality improvement. Therefore, percentage increase in the respective parameters was calculated using the equation below (Rayori D M., 2023):

$$Percentage\ increase = \left(\frac{\text{Conc. of polluntant in effluent} - \text{conc. of pollutant in inffluent}}{\text{Conc. of effluent}}\right) \times 100$$

Equation 3

Compliance and Compliance Index

To assess compliance, effluent discharge physical, chemical, and coliform data were compared with the national (NEMA) and international (WHO and EPA) requirements. To demonstrate how well the treatment plant design polished wastewater it receives, the compliance index value was computed. If the index value was less than 1 (<1), it meant that the effluent discharge regulations were being met. Conversely, non-compliance with the established limits for effluent discharge into the environment or surface water was inferred if the index value was greater than 1 (>1). The following formula was used to calculate the compliance index using NEMA maximum threshold values (Rayori D M., 2023):

$$Compliance\ index = \left(\frac{Conc.of\ pollunt\ effluent}{Maximum\ allowable\ value}\right)$$

Equation 4

Results

Physical and Chemical Parameters Variations

The averages and standard errors (S.E.) of the wastewater physical, chemical, and coliform parameters measured at the several sampling sites in the Suneka WSP during the study period are summarized in Table 1., together with the ranges (minimum and maximum values) in brackets and ANOVA comparisons.

The mean levels and ranges for pH, Temperature, DO, TN and TP had an increasing trend between the influent and effluent. Moreover, their concentrations levels differed significantly (ANOVA $P < 0.05$). TSS, SiO_2, and NH_4-N levels similarly had an increasing trend between the influent and effluent but the levels did not differ significantly (ANOVA $P > 0.05$). There was significant difference in EC, NO_2-N and NO_3-N concentration levels between the influent and effluent sites (ANOVA $P < 0.05$). In terms of trends, they all showed a decreasing trend as the wastewater under went polishing. On the other hand, TDS, and SRP had a similar trend, but their concentrations were not significantly different between the two sampling sites (ANOVA $P > 0.05$) (Table 1).

All the samples which were collected from the WSP including those collected from the river had coliform. With minimum and highest values of 11 and 85 counts/100ml, the mean TC measured was 37.64 ± 3.3 counts/100ml. In contrast to the effluent (35.0 ± 8.5 counts/100 ml), the influent sampling site had the highest mean (57.0 ± 14.8 counts/100 ml). In comparison to the downstream sampling site, the upstream sampling site had a lower mean for TC counts. Comparing the influent and effluent sampling sites, the mean TC counts generally indicated a decrease in total coliform counts, indicating that the wastewater was being polished as it went through the WSP system. However, the mean TC counts did not differ significantly among the sampling sites according to One-way ANOVA (ANOVA $p > 0.05$) (Table 1).

Similar to TC, fecal coliform was also present in the samples which were collected from the WSP and Riana river sites. With minimum and maximum values of 0 to 60 counts/100ml, the mean FC measured was 17.94 ± 2.3 counts/100ml. The downstream sampling site had a higher FC mean (17.25 ± 2.1 counts/100ml) compared with upstream sampling site (10.5 ± 1.8 counts/100ml). Comparing the influent and effluent sampling sites, the mean FC counts generally indicated a decrease in fecal coliform counts, indicating that the wastewater was being polished as it went through the WSP system. However, the mean FC counts did not differ significantly among the sampling sites according to One-way ANOVA (ANOVA $p > 0.05$) (Table 1).

Along Riana River sampling sites, it is only EC, TSS, NO_2-N, and coliforms (TC and FC) concentrations showed an increasing trend between the upstream and downstream sampling sites. However, Single-factor ANOVA showed that they did not differ significantly between the sampling sites (ANOVA $P > 0.05$) (Table 1).

Table 1: The Suneka WSP wastewater polishing

Parameters	Sampling sites			
	Influent	**Effluent**	**Upstream**	**Downstream**
pH	7.33 ± 0.08^{B} (6.92-7.90)	7.77 ± 0.06^{A} (7.29-7.95)	7.45 ± 0.08^{B} (6.84-7.82)	7.27 ± 0.1^{B} (6.58-7.62)
EC (µScm^{-1})	1097.75 ± 128.32^{A} (583.00-2134.00)	665.58 ± 41.17^{B} (444.00-827.00)	115.75 ± 2.27^{C} (99.00-126.00)	146.67 ± 10.23^{C} (105.00-209.00)
Temp (°C)	22.1 ± 0.34^{B} (20.00-23.70)	26.1 ± 0.16^{A} (25.70-27.20)	22.6 ± 0.5^{B} (21.30-27.10)	21.9 ± 0.3^{B} (20.00-24.00)
DO (mgL^{-1})	0.2 ± 0.04^{B} (0.10-0.40)	2.7 ± 0.76^{A} (0.60-7.20)	3.3 ± 0.59^{A} (0.50-6.60)	3.3 ± 0.67^{A} (0.50-7.30)
TSS (mgL^{-1})	65.34 ± 7.4^{A} (26.99-95.30)	77.16 ± 6.0^{A} (42.38-90.90)	73.33 ± 14.9^{A} (10.88-124.00)	79.78 ± 13.2^{A} (12.60-132.00)
TDS (mgL^{-1})	438.3 ± 79.5^{A} (77.20-970.00)	259 ± 42.5^{A} (41.70-414.00)	107.5 ± 1.9^{B} (49.00-72.32)	67.1 ± 6.7^{B} (34.00-104.00)
SiO_2 (mgL^{-1})	20.6 ± 5.3^{A} (1.98-44.62)	21.3 ± 2.1^{A} (15.32-32.68)	25.3 ± 4.2^{A} (0.50-30.56)	21.3 ± 3.3^{A} (10.30-38.88)
SRP (µgL^{-1})	664.8 ± 202.46^{A} (0.32-1477.71)	557.0 ± 137.95^{A} (158.32-1275.86)	452.3 ± 23.53^{B} (0.63-192.00)	$270.5 \pm 60.67^{A,B}$ (127.20-617.71)
NH_4-N (µgL^{-1})	37.7 ± 14.31^{A} (4.67-119.31)	276.9 ± 141.30^{A} (3.54-1088.54)	271.8 ± 50.15^{A} (0.84-386.23)	87.8 ± 44.45^{A} (0.56-343.15)
NO_2-N (µgL^{-1})	$20.2 \pm 1.44^{A,B}$ (12.35-25.90)	8.4 ± 0.99^{B} (3.16-12.74)	43.8 ± 7.47^{A} (12.35-78.03)	56.0 ± 10.03^{A} (9.54-89.87)
NO_3-N (µgL^{-1})	$62.9 \pm 11.81^{A,B}$ (23.16-111.77)	26.4 ± 4.77^{B} (6.95-42.44)	147.0 ± 26.19^{A} (11.54-218.56)	104.5 ± 23.32^{A} (13.43-207.15)
TN (µgL^{-1})	$236.2 \pm 28.84^{A,B}$ (82.32-351.00)	390.7 ± 64.88^{A} (177.38-745.21)	226.6 ± 39.7^{B} (89.20-420.46)	110.1 ± 21.93^{B} (61.80-236.00)
TP (µgL^{-1})	801.0 ± 300.12^{B} (20.69-2459.72)	2557.0 ± 172.55^{A} (1592.57-2988.29)	2378.0 ± 415.28^{A} (125.36-3710.20)	$1943.0 \pm 358.41^{A,B}$ (866.86-3699.71)
Total Coliform (counts/100m)	57.00 ± 14.8^{A} (15-250)	35.00 ± 8.5^{A} (12-90)	25.00 ± 8.5^{A} (31-70)	36.75 ± 8.3^{A} (21-69)
Fecal Coliform	34.25 ± 12.2^{A}	10.50 ± 2.6^{A}	10.50 ± 1.8^{A}	17.25 ± 2.1^{A}

(counts/100m)	(9-250)	(7-75)	(10-65)	(4-75)

Where: The figures in brackets are the ranges. Superscript letters (A, B) in each row indicate that the means differed significantly ($p < 0.05$).

Table 2: Suneka WSP wastewater treatment efficiency

Parameters	Influent	Effluent	% Increase/ Reduction	Compliance index	NEMA	WHO	EPA
pH	7.33±0.08	7.77±0.06	5.7**	0.91	6.5-8.5	6.5-8.5	6-9
EC (μScm^{-1})	1097.75±128.32^{a}	665.58±41.17	39.4	0.33	≤2000	1000	1500
Temp (°C)	22.1±0.34	26.1±0.16^{a} (25.70-27.20)	15**	0.75	25 - 35	Ambient	< 40
DO (mgL^{-1})	0.2±0.04	2.7±0.76	92.6**	-	*	> 4	
TSS (mgL^{-1})	65.34±7.4	77.16±6.0	18**	2.57	≤30	50	50
TDS (mgL^{-1})	438.3±79.5	259±42.5	41	0.22	1200	500	1000
SiO_2 (mgL^{-1})	20.6±5.3	21.3 ±2.1	3**	-	*		
SRP (μgL^{-1})	664.8±202.46	557.0±137.95	16	-	*		1000
NH_4-N (μgL^{-1})	37.7±14.31	276.9±141.30	634**	0.003	100,000		1000
NO_2-N (μgL^{-1})	20.2±1.44	8.4± 0.99	58	0.0001	100,000		1000
NO_3-N (μgL^{-1})	62.9±11.81	26.4±4.77	58	0.0003	100,000	40000	10000
TN (μgL^{-1})	236.2±28.84	390.7±64.88	65**	-	2Guideline value		50000
TP (μgL^{-1})	801.0±300.12	2557.0±172.55	219**	1.28	≤2000	500	2000
Total Coliform (counts/100m)	57.00±14.8	35.00±8.5	38.6		≤30		
Fecal Coliform (counts/100m)	34.25±12.2	10.50±2.6	69.3		Nil		

Where: *** denotes increase in percentage of the respective parameter between the influent and effluent. – denotes compliance index was not calculated for the corresponding parameter due to the lack of NEMA standard limit for the corresponding parameter. * Denotes non-existence of a NEMA standard for the concentration levels of the corresponding parameter [8].*

Wastewater Treatment Efficiency and Compliance

The Suneka WSP performance in wastewater polishing efficiency was evaluated by calculating the percentage increase or reduction of the respective physical, chemical, and coliforms parameter and the results obtained are as shown in Table 2. Additionally, the effluent characteristics were compared to international (WHO and EPA) and national (NEMA) standards for compliance; the findings are displayed in Table 2.

From the results obtained Table 2, there was a general increase in the levels of pH, temperature, and DO in the effluent compared to the influent with percentage increases 5.7%, 15%, and 92.6% respectively as expected as a sign of wastewater polishing. The percentage removal for EC and TDS were 39.4% and 41% in that order.

Silicates had a minimal 3% increase in nutrients in the influent to effluent, whereas SRP showed a 16% decrease. The ammonium-nitrogen ratio increased by 634% compared to the influent. The effluent showed a 58% reduction in the influent nitrite-nitrogen. Similarly, during polishing, wastewater's nitrate-nitrogen value decreased by 58%. However, there was a slight 65% rise in TN levels between the influent and effluent sampling sites. There was a significant 219% increase in TP between the influent and effluent sampling sites (Table 2)

Temperature, EC, pH, TDS, and NO_3-N were all within the allowable maximum set standards of NEMA, EPA, and WHO for effluent discharge to the environment. Additionally, their compliance indices were below 1, which suggests good WSP polishing and compliance. However, TSS and TP's compliance indices were above 1, which indicates non-compliance, and they exceeded the NEMA set limits. Additionally, TSS, and TP surpassed both WHO and EPA set standards. It was impossible to determine if the discharged effluent generally complied with the established requirements for the other parameters due to the absence of NEMA standard limits for the respective parameter consequently, their compliance indices were neither calculated nor referenced for the WSP. TN, SRP, NO_2-N, and NH_4-N measured means in the effluent met the set EPA limits while the mean of TP (2557 ± 172.55 μgL^{-1}) was above WHO (500 μgL^{-1}), and both for NEMA, and EPA (2000 μgL^{-1}) maximum set limits (Table 2).

The coliform levels were reduced as the wastewater underwent treatment in the WSP with FC recording a percentage reduction of 69.3% and TC of 38.9% between the influence and the effluent sampling sites. Despite their reduction in the effluent, the coliform levels exceeded the maximum limits set by the NEMA for effluent discharge to surface waters Table 2.

Discussion

Wastewater is rich with pollutants grouped into physical, chemical, heavy metals, oil and grease, biological (microorganisms) and emerging pollutants like microplastics, pesticides, pharmaceutical and their transformed products (Douglas *et al*.,2024; Unesco, 2017; Yazdanbakhsh *et al*.,2020). For safe reuse for domestic, agricultural, and industrial purposes, or disposal to the environment, therefore, there is need for wastewater polishing. Wastewater treatment efficiency is evaluated by the level of pollutant removal as the wastewater undergoes polishing before effluent discharge to the environment. In addition, the discharged effluent must meet the national and international standards for effluent discharge. In developing countries, wastewater treatment has been poorly managed resulting into health hazards to human and animals and causing environmental degradation (Kumar, Dahms, Won, Lee, & Shin, 2015; Unesco, 2017).

In the Tropics, wastewater stabilization ponds are common in domestic and municipal wastewater treatment due to their low cost of operation, favourable climate, low-maintenance, and sustainability (Amoatey & Bani, 2011). Moreover, to an extent they are efficient in wastewater treatment but with inefficiencies discharging effluents which do not meet local, national, and international required effluent standards (Rayori D M., 2023). For instance, the levels of TN, TP, heavy metals, and coliforms in discharged effluents from WSPs exceeded the required standards (Atwebembeire *et al.,*2019; Nikuze, Niyomukiza, Nshimiyimana, & Kwizera, 2020; Omondi, 2019; Ronoh, 2017; Wanjohi *et al*.,2019). Their inefficiencies in wastewater polishing have been associated with land size, increased sewage wastewater loading, capital, energy, and poor management of the treatment plants among others (Rayori D M., 2023). The means by which pollutants are removed are through physical, chemical, and biological processes. Physical processes include filtration, sedimentation, vitalization and adsorption while chemical processes include hydrolysis, precipitation, and redox reactions. The biological processes of pollutant removal include microbial and algal metabolism (Rayori D M., 20203).

The Suneka WSP is a lagoon. Previous studies conducted in plant showed that the plant was inefficient in polishing wastewater, resulting in Riana river water pollution consequently necessitated its renovation and expansion (during the year 2019-2021) with the intent of improving its efficiency in wastewater polishing and the effluent discharged to be within the maximum allowable limits by NEMA and international standards (Rayori D M., 2023). Therefore, in the current study we evaluated whether the WSP efficiently polished the wastewater it received following its renovation and expansion as envisaged by the WSP's management.

From the results obtained, the WWTP's pollutant removal was generally low for most of the parameters with their percentage reduction being below 60%. Nevertheless, the pollutant reduction, however small, indicates that the quality of wastewater improved as it underwent polishing through the lagoon before being discharged into river Riana as expected (Rayori D M., 2023). The low levels of pollutant removal are attributable to the increased sewage wastewater volume rich with organic and organic pollutants linked to increased human population in the town, large number of institutions that's medical, research, teaching, and poor operation and maintenances of the ponds for example delayed sludge removal (Agoro, Adeniji, Adefisoye, & Okoh, 2020; Nikuze *et al*.,2020). These findings in low level pollutant removal (< 60%) in the WSP are contrary to the findings in the studies conducted in Moi University (Ronoh, 2017), University of Eldoret (Wanjohi *et al*.,2019), and Gacuriro Vision City, Rwanda WSPs whereby the majority of the pollutant reduction percentages were above 60% (Nikuze *et al*.,2020). These pollutants end up in the environment including rivers (Emily, Mainya, Mosoti, & Evans, 2023; Igbinosa & Okoh, 2009; Kinuthia, Ngure, Beti, Lugalia, & Wangila, 2020).

The effluent values of temperature, pH, TDS, NH_4-N, NO_3-N, and NO_2-N released from the WSP were all under the maximum permitted limits with respect to compliance with the NEMA, WHO, and EPA criteria for effluent discharge to the environment; their compliance indices were below 1 (< 1). We were unable to determine if the discharged effluent complied with the established requirements for the remaining parameters since there were no NEMA standard limits for the corresponding parameters. Additionally, the plant's corresponding compliance indices were neither computed nor cited. These results are consistent with other research (Wanjohi *et al*.,2019).

Conclusions and Recommendations

Based on the study findings, it can be concluded that Suneka WSP polishes the wastewater it receives from Kisii municipality and its environs. The effluent levels of DO, pH, TDS, SRP, NO_2-N, and NO_3-N and coliforms met the standard maximum limits of NEMA, EPA, and WHO and their compliance indices were below 1 despite their respective pollutant reduction percentages being low. The improvement in the WSP in wastewater polishing can be attributed to the renovation of the plant and improvement on the wastewater management. Nevertheless, the design still has difficulties in removing coliforms and nutrients, particularly TP and TN. The management should expand the WSP's capacity to handle the increased volume of wastewater received from the municipality as a result of the population's constant growth and the connection of new homes to the sewer line intended to increase its efficacy in wastewater polishing. This will allow the WSP to meet its goals for discharging treated effluent. In order to further polish the wastewater from the WSP and stop the Riana River from becoming eutrophic due to nutrient enrichment, a wetland with the appropriate macrophytes needs to be built.

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Availability of Data and Materials

The necessary data is available upon request from the corresponding author.

References

Agoro, M. A., Adeniji, A. O., Adefisoye, M. A., & Okoh, O. O. (2020). Heavy Metals in Wastewater and Sewage Sludge from Selected Municipal Treatment Plants in Eastern Cape Province, South Africa. *Water, 12*(10), 2746. https://doi.org/10.3390/w12102746

Amoatey, P., & Bani, R. (2011). "Wastewater management." In *Waste water-Evaluation and management* (pp. 379–398). IntechOpen.

APHA. (2014). *Standard methods for the examination of water and wastewater* (22nd ed.). American Public Health Association, American Water Works Association and Water Environmental Federation.

Aregu M. B. (2022). Industrial Wastewater Treatment Efficiency of Mixed Substrate (Pumice and Scoria) in Horizontal Subsurface Flow Constructed Wetland: Comparative Experimental Study Design. *Air, Soil and Water Research, 15*. https://doi.org/10.1177/11786221211063888

Atwebembeire, J., Andama, M., Yatuha, J., Lejju, J. B., Rugunda, G. K., & Bazira, J. (2019). The Physico-Chemical Quality of Effluents of Selected Sewage Treatment Plants Draining into River Rwizi, Mbarara Municipality, Uganda. *Journal of Water Resource and Protection, 11*, 20-36. https://doi.org/10.4236/jwarp.2019.111002

Bannerji, S. (2014). Sewage-fed fisheries under private ownership in the East Kolkata Wetlands: A Case study. *International Journal of Advancements in Research and Technology, 3*(6), 24-34.

Cherotich , E., Nyabaro, O., Rayori, D. M., & Evans, K. O. (2023). Assessment of Chemosit River pollution with urbanization of Chemosit Centre, Kericho County, Kenya . *Pan Africa Science Journal, 3*(02). https://doi.org/10.47787/pasj.v3i02.19

Darko, G., Azanu, D., & Logo, N. K. (2016). Accumulation of toxic metals in fish raised from sewage-fed aquaculture and estimated health risks associated with their consumption. *Cogent Environmental Science, 2*(1), 1190116. https://doi.org/10.1080/23311843.2016.1190116

Douglas Mosoti, R., Obed, N., Albert, G., Reuben, O., Paul, O., & Argwings, O. (2024). Phytoplankton Diversity and Heavy Metal Accumulation: A Case of Suneka Wastewater Treatment Plant, Kenya. IntechOpen. https://doi.org/10.5772/intechopen.1006276

Douglas, R., Albert, G., Reuben, O., Paul, O., Hellen, N., Boniface, G., Obed, N., Omondi, A., & Job, O. (2022). Assessment of Heavy Metal Concentrations (Cu, Cd, Pb, and Zn) in Wastewater from Gusii Treatment Plant in Kisii County, Kenya. *Pan Africa Science Journal, 2*(01), 122–138. https://doi.org/10.47787/pasj.v1i02.1

Hart, L. N., Zepernick, B. N., Natwora, K. E., Brown, K. M., Obuya, J. A., Lomeo, D., Barnard, M. A., Okech, E. O., 2022-23 NSF-IRES Lake Victoria Research Consortium, Kiledal, E. A., Den Uyl, P. A., Olokotum, M., Wilhelm, S. W., McKay, R. M., Drouillard, K. G., Sherman, D. H., Sitoki, L., Achiya, J., Getabu, A., Otiso, K. M., Dick, G. J. (2025). Metagenomics reveals spatial variation in cyanobacterial composition, function, and biosynthetic potential in the Winam Gulf, Lake Victoria, Kenya. *Applied and Environmental Microbiology, 91*(2), e0150724. https://doi.org/10.1128/aem.01507-24

Igbinosa, E. O., & Okoh, A. I. (2009). Impact of Discharge Wastewater Effluents on the Physico-Chemical Qualities of a Receiving Watershed in a Typical Rural Community. *International Journal of Environmental Science & Technology, 6*, 175-182. https://doi.org/10.1007/BF03327619

Kilingo, F., Bernard, Z., & Hong–bin, C. (2021). The analysis of wastewater treatment system efficiencies in kenya: a review paper. *International Journal of Scientific and Research Publications (IJSRP), 11*(5), 204-215.

Kinuthia, G. K., Ngure, V., Beti, D., Lugalia, R., Wangila, A., & Kamau, L. (2020). Levels of heavy metals in wastewater and soil samples from open drainage channels in Nairobi, Kenya: community health implication. *Scientific Reports, 10*, 8434. https://doi.org/10.1038/s41598-020-65359-5

Kumar, D., Chaturvedi, M. K., Sharma, S. K., & Asolekar, S. R. (2015). Sewage-fed aquaculture: a sustainable approach for wastewater treatment and reuse. *Environmental Monitoring and Assessment, 187*(10), 656. https://doi.org/10.1007/s10661-015-4883-x

Laffite, A., Kilunga, P. I., Kayembe, J. M., Devarajan, N., Mulaji, C. K., Giuliani, G., & Pote, J. (2016). Hospital effluents are one of several sources of metal, antibiotic resistance genes, and bacterial markers disseminated in Sub-Saharan urban rivers. *Frontiers in Microbiology, 7*, 1128. https://doi.org/10.3389/fmicb.2016.01128

Morsy, K. M., Mostafa, M. K., Abdalla, K. Z., & Galal, M. M. (2020). Life cycle assessment of upgrading primary wastewater treatment plants to secondary treatment including a circular economy approach. *Air, Soil and Water Research, 13*, 1178622120935857.

Nikuze, M. J., Niyomukiza, J., Nshimiyimana, A., & Kwizera, J. (2020). Assessment of the efficiency of the wastewater treatment plant: A case of Gacuriro Vision City. *IOP Conference Series: Earth and Environmental Science, 448*(1), 012046. https://doi.org/10.1088/1755-1315/448/1/012046

Omondi, A. O. (2019). *Diversity, Distribution and Biomass of Phytoplankton in Lake Naivasha, Kenya* [Master's thesis, Kisii University]. http://localhost:8080/xmlui/handle/123456789/8367

Omondi, A., & Merceline, A. (2023). Invasive Species and their Impacts on the Ecology of Lake Victoria: A Rapid Review. *Pan Africa Science Journal, 3*(02). https://doi.org/10.47787/pasj.v3i02.22

Omweno, J. O., & Omondi, A. (2024). Recent Developments in Fish Nutrition and Culture Technologies in Kenya. IntechOpen. https://doi.org/10.5772/intechopen.112192

Onderi, Z., & Ongori, M. (2019). *Kisii county government finance and economic planning annual development plan (2020-2021).*

Owino, O. A., Mokua, O. G., James, O. M., Omondi, O. S., Omondi, R., & Ombiro, O. J. (2020). Phytoplankton community structure and ecology in Lake Naivasha, Kenya. *International Journal of Fisheries and Aquatic Studies, 8*(3), 478-483.

Rayori D, Getabu A, Omondi R, Orina P, Gisacho B, Omondi A. (2021). Phytoplankton diversity in Gusii wastewater treatment plant in Kisii County, Kenya. *International Journal of Fisheries and Aquatic Studies, 9*(3), 299-306.

Rayori, D. M. (2023). *Assessment of Efficiency of Wastewater Treatment Based on Physico-Chemical and Biological Parameters of Kisii Town Wastewater Treatment Plant, Kenya* [Doctoral thesis, Kisii University]. http://localhost:8080/xmlui/handle/123456789/764

Rayori, D. M., Nyabaro, O., Getabu, A., Omondi, R., & Orina, P. (2024). Evaluation of Suneka Wastewater Treatment Plant Based on the Efficiency of Coliform Bacteria Removal. *Pan Africa Science Journal, 4*(03). https://doi.org/10.47787/pasj.v4i03.77

Rayori, D. M., Omondi, R., Getabu, A., Orina, P., & Omondi, A. (2023). Spatial-Temporal Variations of Zooplankton in Relation to Selected Limnological Parameters: A Case of Kisii Town Wastewater Treatment Plant, Kisii County, Kenya. *Pan Africa Science Journal, 3*(02). https://doi.org/10.47787/pasj.v3i02.23

Ronoh, A. K. (2017). *Efficacy of sewage treatment plant in Moi University, Uasin Gishu County, Kenya* [Master's thesis, Moi University]. http://ir.mu.ac.ke:8080/xmlui/handle/123456789/845

Sarah B., Inna N., Hartmann M., Doetterl S., Garland G. (2024). Opportunities and challenges of using human excreta-derived fertilizers in agriculture: A review of suitability, environmental impact and societal acceptance. *Science of the Total Environment, 957*, 177306. https://doi.org/10.1016/j.scitotenv.2024.177306

UNESCO. (2017). *Wastewater the Untapped Resource*. The United Nations World Water Development Report.

Wanjohi, L., Mwasi, S., Mwamburi, L., & Isaboke, J. (2019). Efficiency of University of Eldoret Wastewater Treatment Plant, Kenya. *Africa Environmental Review Journal, 3*(2), 99-109.

Yazdanbakhsh, A., Alavi, S. N., Valadabadi, S. A., Karimi, F., & Karimi, Z. (2020). Heavy metals uptake of salty soils by ornamental sunflower, using cow manure and biosolids: A case study in Alborz city, Iran. *Air, Soil and Water Research, 13*, 1178622119898460.