E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.549
IJFAS 2021; 9(3): 299-306

www.fisheriesjournal.com
Received: 25-03-2021
Accepted: 27-04-2021

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Phytoplankton diversity in Gusii wastewater treatment plant in Kisii County, Kenya

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DOI: https://doi.org/10.22271/fish.2021.v9.i3d.2505

Abstract
Phytoplanktons are free-floating microscopic plants in water and they are the primary producers providing food to aquatic organisms. However, water quality affects the species production and assemblage in terms of diversity, composition, and abundance. This study assessed the spatial and temporal diversity and abundance of phytoplanktons in the Gusii wastewater treatment plant. A total of 124 phytoplankton species were identified and belonged to six families: Euglenophyceae, Bacillariophyceae, Dinophyceae, Cyanophyceae, Chlorophyceae, and Zygnemophyceae. The phytoplankton biovolume was 385.24mm^3/L, with the family Euglenophyceae contributing the largest percentage. The species diversity index (H') was generally low (H' = 1.759 and 0.7596) in the effluent and influent respectively, indicating a considerable increase in diversity as the wastewater undergoes treatment. The low diversity was attributed to changes in physical, chemical, and biological environmental conditions. The effluent was richer in species, with a value of 5.829, while the influent was the least with 3.409. The low phytoplankton diversity in the wastewater treatment plant was influenced by the physicochemical parameters. It is therefore recommended that the quality of the wastewater during treatment needs to be monitored continuously for quality as baseline information to guide stakeholders and to ensure sustainability for the Gusii wastewater lagoon ecosystem health.

Keywords: wastewater, water quality, phytoplankton, diversity

1. Introduction
Phytoplanktons are free floating microscopic plants in water and they are the primary producers providing food to aquatic organisms [1]. Moreover, the phytoplankton do play an important role in wastewater treatment [2]. However, water quality affects the species production and assemblage in terms of diversity, composition, and abundance. Hence, phytoplankton community can be used as a bio-indicator of the health status of the wastewater during the treatment process in the ponds [3].

Wastewater is of poor quality as it is rich with pathogenic micro-organisms, heavy metals, organic and inorganic chemicals, and toxic substances thus not suitable for domestic use and to the environment unless treated [4]. In developing countries, Waste Stabilizing Ponds (WSPs) are the most commonly used for domestic and municipal wastewater treatment because of their low cost of operation, favorable climate, low-maintenance, highly efficiency, and sustainability. In WSPs, wastewater goes through a series of ponds [5]. In General, before the wastewater is released to WSPs, the water goes through preliminary screening and grit removal mainly to get rid of large and heavy solids. The primary and secondary treatment takes place in the anaerobic and facultative ponds, respectively to remove organic matter, *Vibrio cholerae*, and helminth eggs. In the maturation ponds, fecal viruses, bacteria, and nutrients are removed [5, 6]. Normally, the effluent from the plant is discharged to the environment usually flowing waters. The receiving waters are usually impacted negatively in terms of water quality and biota composition [7].

Gusii Wastewater treatment plant is a lagoon system with its effluent discharged into river Riana. During the study period, the design system had a single series of functional ponds with a design capacity of the lagoon being 1500m^3/day of wastewater from Kisii town and its environs (http://www.gwasco.co.ke/waterschemes).

Effluent discharge into the river is of concern due to its perceived contamination. This study was undertaken to assess the phytoplankton diveristy and selected physical chemical parameters in the treatment plant.

2. Materials and Methods

2.1 Study area

This study was carried out at the Gusii wastewater treatment plant which is a lagoon system. The physical location of the plant is Suneka Division at latitude 0^0 39' 30'' S and Longitude 34^0 42' 30'' E. The design capacity of the lagoon is 1500m^3/day of wastewater from Kisii town and its environs. Currently, the plant system is under expansion to optimize its treatment capacity due to increasing influent. The current system has a single series of functional ponds. Before the wastewater enters the ponds, it goes through the receiving units in screens, grit chambers to remove debris, and channels to the ponds. Then the water goes through the anaerobic, facultative, and tertiary ponds for treatment before being discharged into river Riana (Figure 1).

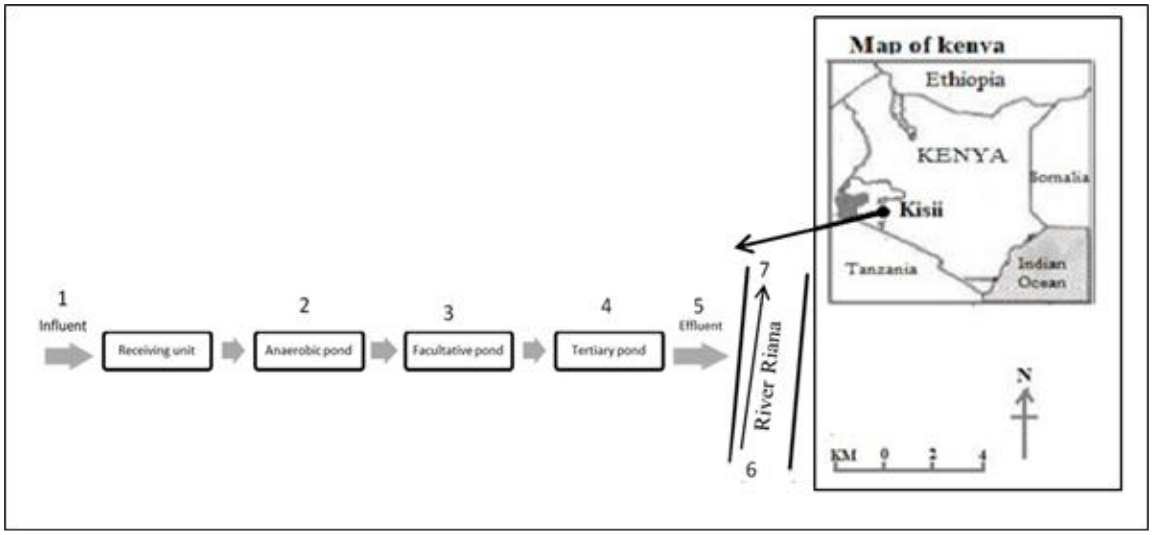

Fig 1: A sketch showing the wastewater treatment stages and sampling points in Gusii wastewater treatment plant (Author).

2.2 Sampling

In this study we used field surveys, *in situ* measurements, and descriptive surveys for five months. Sampling for wastewater analysis was done between August and December 2019. Wastewater samples were collected from seven points which include inlet (Influent), anaerobic, facultative, and tertiary ponds including the effluent before discharge into the river besides to two points in the river that's 100 meters up and downstream at the effluent discharge point into the river. At each sampling point, wastewater samples were collected in triplicate that gave rise to a total of 21 samples per sampling session. Normally, sampling was done between 8-10.00 am. Wastewater samples were collected in pre-cleaned 500ml plastic bottles at the sub-surface level and analyzed at Kenya Marine and Fisheries Research Institute (KMFRI), Kisumu laboratory following procedures as outlined in the standard method for the examination of water and wastewater [8].

2.3 Physico-chemical parameters

The parameters that were determined include temperature (^{0}C), pH, electrical conductivity (µScm^{-1}), dissolved oxygen (DO) (mgL^{-1}), and nutrients. The pH, temperature, electrical conductivity, and DO were measured *in situ* at each sampling site using portable professional series (YS1) multi-parameter meter. Wastewater samples for analysis of nutrients were collected in triplicate and transported in a cool box to the laboratory for analysis using the spectrophotometric method for the determination of water and wastewater as described in APHA (1999).

2.4 Phytoplankton analysis

For phytoplankton identification, wastewater samples were collected in triplicate in pre-cleaned 500ml plastic bottles at the sub-surface level and analyzed at Kenya Marine Fisheries Research Institute (KMFRI), Kisumu laboratory. The samples were immediately fixed after collection with 1% acidic Lugol's solution and allowed to settle overnight in an Utermöhl sedimentation chamber. Microscopic examination technique was used for phytoplankton species identification and enumeration. The Zeiss Axioinvert 35 inverted microscope was used at 400x magnification. Identification of phytoplankton taxa was done by following the methods by Huber-Pestalozzi *et al.* [9] and Cocquyt *et al.* [10] to the genus and species level where possible.

2.5 Determination of phytoplankton diversity

To determine the phytoplankton diversity and abundance across the different sampling stations, three diversity indices were computed (Shannon-Wiener (H'), Margalef's Index (d), and species evenness) by following formulas according to Ogbeigbu [11] and Eyo *et al.* [12].

Shannon-Wiener Index $H' = \sum_i P_i Ln_i\ P_i$

Where P_i is the proportion (n/N) of all the phytoplankton which belongs to the i^{th} species, Ln is the natural log and ∑ is the sum of the calculation.

In the Shannon-Wiener Diversity Index computation, it is assumed that all species are represented in a sample and are randomly selected. Also, it accounts for both the abundance and evenness of the species present.

Margalef's Index (d) determined as; $d = \frac{s-1}{Ln(N)}$

Where S is the total number of species, Ln is the Natural log and N is the total number of individuals.

Evenness (E) was given as; $E = \frac{H}{\log S}$

Where H is the Shannon-Wiener index, and S is the total number of species

2.6 Data analysis
Spatial and temporal differences in the physico-chemical parameters and phytoplankton abundance were determined by One-way Analysis of Variance (ANOVA) at a pre-determined *alpha* value of 0.05 using Microsoft Excel version 2010 to test for significant differences. Where the means were significant, *post hoc* analysis was done using the Tukey pairwise comparisons under Minitab version 18 to establish where the differences existed between the sampling stations and months. The Microsoft Excel version 2010 and PAST software were used to compute the phytoplankton diversity indices.

3. Results
3.1 Spatial variation of the physico-chemical parameters
3.1.1 Temperature
The temperature of the sampling stations ranged from 22.27 ^{0}C ± 0.56 to 26.53 ^{0}C ± 2.68 SD. One way ANOVA test showed that mean temperature was significant among the stations ($F_{(6, 21)}$ =7.5178; p = 0.0002) (Table 1). *Post hoc* Tukey Pairwise Comparisons revealed that the mean temperature of influent was lower by between 1.925 ºC and 6.011 ºC than that of tertiary. For anaerobic, the mean temperature was lower by between 0.235 ºC and 4.320 ºC than that of tertiary. On the other hand, the mean temperature for the facultative was higher by between 2.217 ºC and 6.303 ºC than that of the influent. For the effluent, the mean temperature was higher by between 1.623 ºC and 5.709 ºC than that of the influent.

3.1.2 pH
The effluent had a mean pH of 7.14 ± 1.65 SD, compared with the influent with mean of 6.54 ± 2.24 SD and river point 1 showed the highest mean of pH of 7.73 ± 0.20 SD (Table 1). One way ANOVA test showed their was no significant differences among sampling stations ($F_{(6, 21)}$ = 0.3318; p = 0.9125).

3.1.3 Dissolved oxygen
The effluent had a mean dissolved oxygen of 5.57 Mg/L ± 4.1 SD which was high compared with the influent mean 2.00 Mg/L ± 2.7 SD of dissolved oxygen while the anaerobic pond had the least mean dissolved oxygen of 0.41 Mg/L ± 0.4 SD (Table 1). One way ANOVA indicated no significant differences between the sampling stations ($F_{(6, 21)}$ = 2.2862; p = 0.0743).

3.1.4 Conductivity
The influent mean conductivity was the highest with 1404.0 µscm^{-1} ± 1239 SD, followed by the tertitiary pond with 926.1 µscm^{-1} ± 297 SD then facultative pond station with mean of 888.0 µscm^{-1} ± 305 SD and the anaerobic pond station with mean conductivity of 878.9 µscm^{-1} ± 290 SD. The river point 1 station recorded the lowest mean conductivity of 128.2 µscm^{-1} ± 23 SD while river point 2 station had a mean 240.3 µscm^{-1} ± 136 SD of conductivity (Table 1). One way ANOVA test showed that conductivity was statistically significant ($F_{(6, 21)}$ =2.9388; p = 0.03051) among the sampling stations. *Post hoc* Tukey Pairwise Comparisons revealed that Conductivity mean for effluent was lower by between 190.6 µscm^{-1} and 1385.2 µscm^{-1} than that of influent.

Table 1: Mean spatial variation in physico-chemical parameters for Gusii wastewater treatment plant with standard deviation (± SD)

Parameters	Stations							
	Influent	**Anaerobic**	**Facultative**	**Tertiary**	**Effluent**	**River point 1**	**River point 2**	***P-value***
Temp (^{O}C)	22.27±0.56	23.96±0.98	26.53±2.68	26.23±1.19	25.93±1.42	22.61±0.76	22.68±0.81	0.0002
pH	6.54±2.24	6.04±2.60	6.78±2.86	7.20±2.31	7.14±1.65	7.73±0.20	7.51±0.62	0.9125
DO(Mg/L)	2.00±2.7	0.41±0.4	4.45±4.6	3.07±2.2	5.57±4.1	5.64±3.9	7.11±0.7	0.0743
Conductivity (µscm^{-1})	1404.0±1239	878.9±290	888.0±305	926.1±297	616.1±124	128.2±23	240.3±136	0.0305
NO_2-N (µg/L)	43.31±34.1	19.18±14.4	19.34±16.2	30.51±23.1	35.45±27.2	79.28±110.9	135.89±198.2	0.5012
NO_3-N (µg/L)	67.08±45.8	58.08±41.0	31.11±8.5	44.72±22.9	45.73±27.7	110.04±89.5	192.74±259.7	0.3932
NH_4-N (µg/L)	464.1±554.4	674.0±511.1	1090.0±639.9	987.1±542.8	776.1±418.3	813.9±772.2	605.1±459.0	0.7403
SRP (µg/L)	1121.0±240.9	725.4±830.9	1002.1±396.3	803.6±551.5	479.9±334.1	402.0±708.0	209.0±283.8	0.1950
TP (µg/L)	1604.23±726.3	1272.28±954.7	1824.9±1248.4	1542.23±1385.8	1443.38±934.0	859.66±800.6	1019.53±609.2	0.8232
TN (µg/L)	800.1±730.4	409.0±221.1	1280.7±875.9	1231.4±996.3	1080.5±951.4	764.7±740.7	856.1±1011.3	0.7727

3.1.5 Nutrient concentrations
The influent showed a high mean nitrite and nitrate-nitrogen concentration of 43.31 µg/L ± 34.1 SD and 67.08 µg/L ± 45.8 SD respectively compared to the effluent discharge from the treatment plant which had a lower mean nitrite and nitrate-nitrogen of 35.45 µg/L ± 27.2 and 45.73 µg/L ± 27.7 SD respectively. The measured nitrite-nitrogen mean for the anaerobic, facultative and tertiary stations were 19.18 µg/L ± 14.4 SD, 19.34 µg/L ± 16.2 SD and 30.51 µg/L ± 23.1 SD respectively. The mean nitrate-nitrogen for anaerobic, facultative and tertiary stations were 58.08 µg/L ± 41.0 SD, 31.11 µg/L ± 8.5 SD and 44.72 µg/L ± 22.9 SD respectively (Table 1). One way ANOVA showed that nitrite-nitrogen was not significant among the sampled stations ($F_{(6, 21)}$ = 0.9188; p = 0.5012). Similary, one way ANOVA for nitrate-nitrogen among the sampled stations was not significant ($F_{(6, 21)}$ = 1.1033; p = 0.3932) either.

The facultative station had the highest mean ammonia-nitrogen of 1090.0 µg/L ± 639.9 SD while the influent station had the least mean ammonia-nitrogen of 464.1 µg/L ± 554.4 SD (Table 1). One way ANOVA indicated no significant differences between the sampling stations ($F_{(6, 21)}$ = 0.5824; p = 0.7403) for ammonia-nitrogen concentrations.

Influent sampling station showed the highest mean SRP of 1121.0 µg/L ± 240.9 SD, followed by facultative station with 1002.1 µg/L ± 396.3 SD, then tertiary station with 803.6 µg/L ± 551.5 SD, and the anaerobic sampling station had SRP mean of 725.4 µg/L ±830.9 SD. Also, the effluent discharge had SRP mean of 479.9 µg/L ± 334.1 SD. For the river sampling point 1 and 2 showed mean of 402.0 µg/L ±708.0 SD and 209.0 µg/L ± 283.8 SD respectively (Table 1). One way ANOVA showed that SRP was not significant among the

sampled stations ($F_{(6, 21)} = 0.16053$; $p = 0.1950$).
The effluent station recorded TP mean of 1443.38 µg/L ± 934.0 SD which was lower compared to the influent station TP mean of 1604.23 µg/L ± 726.3 SD. For the anaerobic, facultative, and tertiary stations measured TP means were 1272.28 µg/L ± 954.7 SD, 1824.9 µg/L ± 1248.4 SD and 1542.23 µg/L ± 1385.8 SD respectively. While TP mean of 859.66 ± 800.6 SD and 1019.53 ± 609.2 SD were recorded for river point 1 and 2 sampling stations respectively (Table 1). One way ANOVA showed that TP was not significant among the sampled stations ($F_{(6, 21)} = 0.4694$; $p = 0.8232$).
Anaerobic pond sampling station recorded the least mean TN of 409.0 µg/L ± 221.1 SD, followed by the influent station with a mean of 800.1 µg/L ± 730.4 SD, then effluent station with a mean of 1080.5 µg/L ± 951.4 SD, and the tertiary with a mean of 1231.4 µg/L ± 996.3 SD, lastly the facultative station with a mean of 1280.7 µg/L ± 875.9 SD. The river point 1 station had a lower TN mean of 764.7 µg/L ± 740.7 SD compared with the river point 2 station which had TN mean of 856.1 µg/L ± 1011.3 SD (Table 1). One way ANOVA showed that TN was not significant among the sampled stations ($F_{(6, 21)} = 0.5389$; $p = 0.7727$).

3.2 Temporal variation of the physico-chemical parameters

Table 2: shows the mean temporal variation of studied physico-chemical parameters with standard deviation (± SD)

Parameters	August	September	November	December	*P-value*
Temp (^{O}C)	25.23±2.99	24.76±1.91	23.83±2.17	23.44±0.96	0.3922
pH	7.49±0.57	7.95±0.37	8.10±0.39	4.43±2.13	5.938E^{-06}
DO(Mg/L)	6.19±3.6	1.17±2.5	4.73±3.5	4.05±2.9	0.0438
Conductivity (µscm^{-1})	1125.8±1013.4	774.0±448.1	565.3±307.4	438.5±220.5	0.1664
NO_2-N (µg/L)	107.4±167.0	47.2±19.5	17.5±11.2	35.3±26.8	0.2495
NO_3-N (µg/L)	131.32±212.5	78.51±36.4	43.59±21.4	60.58±31.8	0.4839
NH_4-N (µg/L)	750.8±455.5	781.5±579.5	811.2±663.1	748.1±573.3	0.9964
SRP (µg/L)	1032.5±599.4	437±448.2	596.1±635.1	644.7±448.3	0.2310
TP (µg/L)	1866.3±1001.2	1407.5±1165.8	883.7±501.3	1309±840.0	0.2751
TN (µg/L)	1623.5±904	354.1±218	459.1±485.4	1233.3±605.6	0.0013

3.2.1 Temperature
Month of August had the highest mean temperature of 25.23 ^{0}C ± 2.99 SD, followed by September with mean of 24.76 ^{0}C ± 1.91 SD and November recorded a mean of 23.83 ^{0}C ± 2.17 SD. The month of December had the least mean temperature of 23.44 ^{0}C ± 0.96 SD (Table 2). Single factor ANOVA showed that temperature was not statistically significant ($F_{(3, 24)} = 1.0414$; $p = 0.3922$) among the sampled months.

3.2.2 pH
The month of November recorded the highest mean pH of 8.10 ± 0.39 SD, followed by the month of September which recorded a mean of 7.95 ± 0.37 SD. The month of August measured a mean pH of 7.49 ± 0.57 SD and the month of December had the lowest mean of 4.43 ± 2.13 SD (Table 2). Single factor ANOVA showed that pH was statistically significant between the sampling months ($F_{(3, 24)} = 16.1236$; $p = 5.938E^{-06}$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean pH of August was higher by between 2.132 and 3.974 than that of December. For September, the mean pH was higher by between 2.593 and 4.435 than that of December. Similarly, the mean pH for November was higher by between 2.741 and 4.583 than that of December.

3.2.3 Dissolved oxygen
The month of August recorded the highest mean DO of 6.19 Mg/L ± 3.6 SD, followed by the month of November with DO of 4.73 Mg/L ± 3.5 SD, then month of December recorded mean DO of 4.05 Mg/L ± 2.9 SD while the month of September recorded the lowest mean of 1.17 Mg/L ± 2.5 SD. Single factor ANOVA showed that DO was statistically significant between the sampling months ($F_{(3, 24)} = 3.1418$; $p = 0.0438$). *Post hoc* Tukey Pairwise Comparisons revealed that the mean DO of August was higher by between 2.558 Mg/L and 7.489 Mg/L than that of September. For September, the mean DO was lower by between 1.093 Mg/L and 6.024 Mg/L than that of November. Similarly, the mean DO for September was lower by between 0.416 Mg/L and 5.347 Mg/L than that of December.

3.2.4 Conductivity
The recorded mean conductivity for the months of August, September and November were 1125.8 µscm^{-1} ± 1013.4 SD, 774.0 µscm^{-1} ± 448.1 SD and 565.3 µscm^{-1} ± 307.4 SD respectively. The month of December had the lowest mean conductivity of 438.5 µscm^{-1} ± 220.5 SD (Table 2). Single factor ANOVA showed that Conductivity was not statistically significant between the sampling months ($F_{(3, 24)} = 1.8427$; $p = 0.1664$).

3.2.5 Nutrients concentrations
The month of August had the highest nitrite-nitrogen mean of 107.4 µg/L ± 167.0 SD while November had the lowest measured mean of 17.5 µg/L ± 11.2 SD. The recorded nitrite-nitrogen means for the month of September and December were 47.2 µg/L ± 19.5 SD and 35.3 µg/L ± 26.8 SD respectively. Single factor ANOVA showed that nitrite-nitrogen was not statistically significant between the sampling months ($F_{(3, 24)} = 1.4633$; $p = 0.2495$). The highest recorded nitrate-nitrogen concentration mean of 131.32 µg/L ± 212.5 SD was for the month of August. On the other hand, the month of November had the lowest mean of 43.59 µg/L ± 21.4 SD (Table 2). Also, single factor ANOVA showed that nitrate-nitrogen concentration was not statistically significant between the sampling months ($F_{(3, 24)} = 0.8427$; $p = 0.4839$).
The month of August recorded the lowest mean Ammonia-nitrogen of 750.8 µg/L ± 455.5 while the month of November the highest mean of 811.2 µg/L ± 663.1 SD was recorded. For the month of September and December recorded the mean of 781.5 µg/L ± 579.5 SD and 748.1 µg/L ± 573.3 SD respectively (Table 2). Single factor ANOVA showed that Conductivity was not statistically significant between the sampling months ($F_{(3, 24)} = 1.5353$; $p = 0.2310$).
The month of August had the highest SRP mean of 1032.5 µg/L ± 599.4 SD, followed by the month of December with mean of 644.7 µg/L ± 448.3 SD. The month of September recorded mean of 437 µg/L ± 448.2 SD while the month of November had a mean of 596.1 µg/L ± 635.1 SD (Table 2). Single factor ANOVA showed that SRP was not statistically

significant between the sampling months ($F_{(3, 24)} = 0.0188$; $p = 0.9964$).

The month of August recorded the highest mean TP of 1866.3 µg/L ± 1001.2 SD, followed by the month of September with mean of 1407.5 µg/L ± 1165.8 SD and month of December recorded a mean of 1309 µg/L ± 840.0 SD. The month of November recorded the lowest TP mean of 883.7 µg/L ± 501.3 SD (Table 2). Single factor ANOVA showed that TP was not statistically significant between the sampling months ($F_{(3, 24)} = 1.3722$; $p = 0.2751$).

The month of August recorded the highest mean of TN of 1623.5 µg/L ± 904 SD, followed by the month of December with mean of 1233.3 µg/L ± 605.6 SD. The month of November and September recorded mean TN of 459.1 µg/L ± 485.4 SD and 354.1 µg/L ± 218 SD respectively (Table 2). Single factor ANOVA showed that TN was statistically significant between the sampling months ($F_{(3, 24)} = 7.1623$; $p = 0.0013$). . *Post hoc* Tukey Pairwise Comparisons revealed that the mean TN of August was higher by between 773.9-1765.0 µg/L and 668.8-1659.9 µg/L than that of September and November respectively. For September, the mean TN was lower by between 383.7 µg/L and 1374.6 µg/L than that of December. The mean TN for November was lower by between 278.6 µg/L and 1269.7 µg/L than that of December.

3.3 Phytoplankton

A total of one hundred and twenty-four (124) phytoplankton species belonging to six (6) taxonomic groups were identified (Table 3). The family Bacillariophyceae was represented by 36 species consisting of 29 % by species composition, followed by the family Chlorophyceae, which was represented by 34 species consisting of 28 % by species composition. The family Cyanophyceae was represented by 31 species leading to a 25 % species composition. Other taxonomic families included Euglenophyceae, Zygnematophyceae, and Dinophyceae represented by 10 (8%), 9 (7%), and 4 (3%) species respectively.

Table 3: A list of phytoplankton species recorded in Gusii wastewater treatment plant.

Chlorophyceae	Cyanophyceae	Bacillariophyceae
Ankistrodesmus falcatus	*Anabaena circinalis*	*Amphora ovaris*
Botryococcus braunii	*Anabaena flos-aquae*	*Amphora sp*
Coelastrum microporum	*Anabaena limnetica*	*Aulacoseira ambigua*
Coelomoron merostoides	*Aphanocapsa pularva*	*Aulacoseira nyasensis*
Coelomoron reguraris	*Aphanocapsa rivularis*	*Aulacoseira Schroidera*
Coelomoron vestitus	*Aphanothece sp*	*Chodatella longiseta*
Crucigenia menenghiana	*Chodatella longiseta*	*Chodatella sp*
Crucigenia sp	*Chrococcus dispersus*	*Cyclotella kutzinghiana*
Dictyosphaerium sp	*Chrococcus limnetica*	*Cyclotella ocellata*
Kirchnella contorta	*Chrococcus limneticus*	*Cymbella cistula*
Kirchnella lunaris	*Chrococcus turgidus*	*Diatoma elongatum*
Kirchneriella schimidle	*Coelomoron merostoides*	*Diatoma hemiale*
Monoraphidium sp	*Coelomoron vestitoz*	*Euglenophytalena vivids*
Oocystis nageli	*Cylindrospermopsis africana*	*Eunotia flexuosa*
Oocystis parva	*Merismopedia punctata*	*Flagilaria athiopica*
Oscillatoria gemirata	*Merismopedia tennuissima*	*Flagilaria construens*
Oscillatoria tenuis	*Microcystis aeruginosa*	*Fragilaria crotonensis*
Pediastum boryanum	*Microcystis flos-aquae*	*Navicula gastrum*
Pediastum duplex	*Microcystis wasenbergii*	*Navicula granatum*
Pediastum tetras	*Oscillatoria tanganyikae*	*Navicula pupula*
Rhapidium braunii	*Oscillatoria tenuis*	*Navicula salicuta*
Scenedesmus curvatus	*Plankolyngbya tallingii*	*Navicula simplex*
Scenedesmus quadricauda	*Planktolyngbya circumcreta*	*Navicula sp*
Scenedesmus acuminatus	*Planktolyngbya limnetica*	*Nitzschia lacustris*
Scenedesmus maximus	*Planktolyngbya talingii*	*Nitzschia palea*
Scenedesmus obliquus	*Pseudo-anabaena tanganyikae*	*Nitzschia recta*
Scenedesmus quadricauda	*Romeria ankensis*	*Nitzschia sub acicularis*
Scenedesmus quadricuada	*Romeria elegans*	*Pinnularia subcepitata*
Schroidera setigera	*Spirulina princeps*	*Stephanodiscus astrea*
Surillella elegans	*Spirulina sp*	*Stephanodiscus sp*
Tetraedron arthromisforme	*Surillella affins*	*Surillella affins*
Tetraedron inflatum	Euglenophyceae	*Surillella sp*
Tetraedron triangulare	*Euglena acus*	*Surillella tenera*
Tetraedron trigonum	*Euglena Virids*	*Synedra cunningtonii*
Dinophytaphyceae	*Euglenophytalena acus*	*Synedra ulna*
Ceratinium branchyceros	*Euglenophytalena virids*	*Tubellaria sp*
Glenodinium pernardii	*Phacus longicauda*	Zygnemophyceae
Glenordinium pulvasistoz	*Phacus pleuronectes*	*Closterium navicula*
Glenoridinium pernardii	*Phacus sp*	*Cosmarium launderii*
	Strombomonas sp	*Cosmarium lundella*
	Trachelomonas armata	*Cosmarium menenghiana*
	Trachelomonas volvocina	*Cosmarium paradoxum*
		Crucigenia menenghiana
		Crucigenia sp
		Straurastum limnetica
		Straurastum paradoxum

3.4 Phytoplankton Diversity

The least total number of phytoplankton species was recorded in the influent with 32 (10.6%) species, followed by 34 (11.6%) species in River Point 2, followed by 36 (12.2%) species in River Point 1, then by 44 (15.0%) in the anaerobic. The tertiary recorded a total of 47 (16.0%) species, followed by effluent with 50 (17.0%) species, and the facultative recording the highest species number of 51 (17.3%) (Table 4).

Table 4: The phytoplankton species diversity and dominance indices, evenness, and Margalef in the Gusii wastewater treatment plant

	Influent	Anaerobic	Facultative	Tertiary	Effluent	River point 1	River point 2
Taxa (s)	32	44	51	47	50	36	34
Individuals	8887	7026	16094	9079	4473	3448	391
Dominance_D	0.6917	0.5185	0.6787	0.524	0.4125	0.345	0.066309
Shannon_H	0.7596	1.373	0.9265	1.349	1.759	1.54	3.055
Evenness_e^H/S	0.06679	0.08971	0.04952	0.08203	0.1161	0.1296	0.6239
Margalef (Species richness)	3.409	4.855	5.162	5.047	5.829	4.297	5.529

The phytoplankton species diversity index (H') during this study was generally low indicating low diversity. The effluent had a more phytoplankton diversity index (H'=1.759) compared to the influent (H'=0.7596) indicating a considerable increase in diversity as the wastewater undergoes treatment.

The dominant index (D) had a maximum value above 0.6917 on the influent and the effluent with the least value of 0.4125. In terms of Margalef's diversity that's species richness (d), the effluent was richer (with a value of 5.829) while the influent was with the least (3.409). Evenness (E) ranged from 0.04952 at the facultative to 0.1161 at effluent.

3.5 Phytoplankton biomass and distribution

During the study period, the total phytoplankton biovolume of 385.24mm^3/L was recorded with the family Euglenophyceae contributing to 35.864 % of the total phytoplankton biovolume (Table 5). This was followed by the family Dinophytaphyceae with 28.167 % and Cyanophyceae with 15.486 %, and then closely followed by Bacillariophyceae with 15.463 % of the total phytoplankton biovolume. The family Chlorophyceae contributed the least with 3.812 % of the total phytoplankton biovolume (Table 5).

Table 5: Phytoplankton Biovolume in mm^3 per Litre in the Gusii wastewater treatment plant

Taxonomic group	No. of species	Phytoplankton Biovolume (mm^3/L)	Percentage Biovolume (%)
Chlorophyceae	34	14.68	3.812
Cyanophyceae	31	59.66	15.486
Bacillariophyceae	36	59.57	15.463
Dinophytaphyceae	4	108.51	28.167
Euglenophyceae	10	138.16	35.864
Zygnemophyceae	9	4.65	1.208
Total	124	385.24	100.000

In terms of spatial variation, the anaerobic had the highest total phytoplankton biovolume by composition with 27.01 % followed by facultative, tertiary, effluent, influent, river point 1 and 2 with 24.57 %, 20.10 %, 12.70 %, 9.91 %, 3.69 %, and 2.03 % respectively (Table 6).

Table 6: Spatial variation of phytoplankton Biovolume in mm^3 per Litre in Gusii wastewater treatment plant

Sampling stations	No. of species	Phytoplankton Biovolume (mm^3/L)	Percentage Biovolume (%)
Influent	32	38.181	9.91
Anaerobic	44	104.043	27.01
Facultative	51	94.642	24.57
Tertiary	47	77.429	20.10
Effluent	50	48.907	12.70
River point 1	36	14.217	3.69
River point 2	34	7.822	2.03

Temporally, the family Euglenophyceae dominated the months of August and September, while Dinophytaphyceae dominated in the months November followed by August then September but absent in December by biomass. The family Cyanophyceae biomass was high in September, and November but least in August by biomass. The family of Bacillariophyceae they dominated in August, November, and December. The families Chlorophyceae and Zygnemophyceae had a relatively low total phytoplankton biovolume throughout the sampling months (Figure 2).

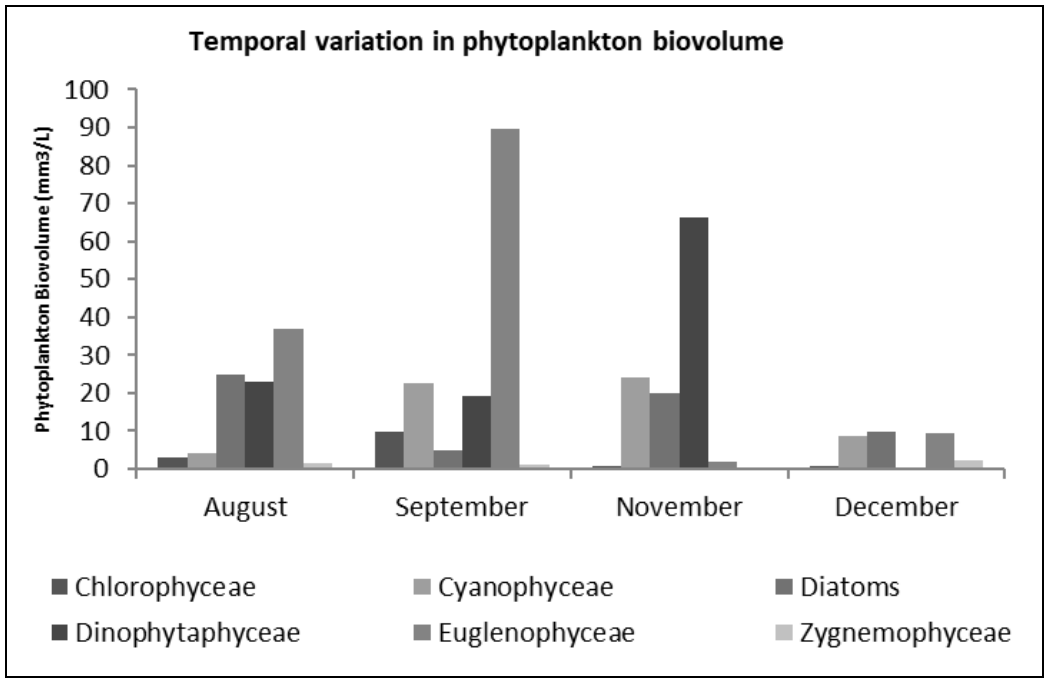

Fig 2: Temporal variation in phytoplankton biovolume of the Gusii wastewater treatment plant

4. Discussion

Wastewater is of poor quality and needs treatment before release to the environment. The effects associated with the release of untreated or partially treated wastewater include degradation of aquatic ecosystems, the outbreak of food and water-borne diseases, and environmental pollution [4]. Nevertheless, treated wastewater reuse has been increasing in the last few years for varied purposes including Agricultural use that's for irrigation, and aquaculture, industrial use, and domestic i.e. for cooking drinking, and washing [4, 5, 6].

Gusii wastewater treatment plant is relatively eutrophic because of the high organic discharge it receives as these results indicate. The increase in the wastewater load to the treatment plant can be attributed to increase in domestic effluent as a result in population increase [6]. Also, high levels of nutrients can be linked to agricultural activities at the catchment area. Moreover, heavy rains might have also led to enrichment of the wastewater with dissolved organic matter during runoff. Due to enrichment of wastewater with nutrients, this had a potential of supporting and at the same time inhibit growth of aquatic fauna and flora [13, 14].

The different sampling stations were different in phytoplankton abundance and diversity however, the values of species diversity index (H') during this study were generally low indicating low diversity but with a few taxa dominating as a result. The Euglenophyta dominated in the influent, facultative, and the effluent while the Bacillariophyceae dominated in the anaerobic pond. On the other hand, the cyanophytes were moderate in all stations. In general, the non-diatomic algae dominated qualitatively and quantitatively and it is in accordance with other previous studies [6, 13, 14]. The low diversity can be attributed to extreme physico-chemical parameters observed in the sampling stations this being in line with other similar studies [15, 17].

5. Conclusion and Recommendation

This study recorded low phytoplankton diversity in the wastewater treatment plant and the non-diatomic algae dominated qualitatively and quantitatively. The low diversity, distribution, and abundance of phytoplankton can be attributed to extreme physico-chemical parameters observed in the sampling stations during the study period. It is therefore recommended that the quality of the wastewater during treatment needs to be monitored continuously for quality as baseline information to guide stakeholders and to ensure sustainability for the wastewater lagoon ecosystem health.

6. References

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