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 Zygmenophyceae. The phytoplankton biovolume was 385.24mm³/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 1500m³/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 diversity 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° 39’ 30” S and Longitude 34° 42’ 30” E. The design capacity of the lagoon is 1500m³/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 Influent (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 (°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 (YSI) 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 \[ H' = \sum P_i \cdot \ln P_i \]

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 \( \sum \) 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:
\[
\text{d} = \frac{s - 1}{\ln(N)}
\]

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 sampled stations ranged from 22.27 °C ± 0.56 to 26.53 °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 higher by between 1.925 °C and 6.011 °C than that of tertiary. For anaerobic, the mean temperature was higher by between 0.235 °C and 4.320 °C than that of tertiary. On the other hand, the mean temperature for the facultative was lower by between 2.217 °C and 6.303 °C than that of the influent. For the effluent, the mean temperature was lower by between 1.623 °C and 5.709 °C 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 \( \mu \text{scm} \) ± 1239 SD, followed by the tertiary pond with 926.1 \( \mu \text{scm} \) ± 297 SD then facultative pond station with mean of 888.0 \( \mu \text{scm} \) ± 305 SD and the anaerobic pond station with mean conductivity of 878.9 \( \mu \text{scm} \) ± 290 SD. The river point 1 station recorded the lowest mean conductivity of 128.2 \( \mu \text{scm} \) ± 23 SD while river point 2 station had a mean 240.3 \( \mu \text{scm} \) ± 136 SD of conductivity (Table 1). One way ANOVA test showed that conductivity was statistically significant (F (6, 21) = 2.3988; \( p = 0.03051 \)) among the sampling stations. Post hoc Tukey Pairwise Comparisons revealed that Conductivity mean for effluent was higher by between 190.6 \( \mu \text{scm} \) and 1385.2 \( \mu \text{scm} \) 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 (°C)    | 22.7±20.56                        | 23.9±0.98        | 26.5±2.68       | 26.2±1.19      | 25.9±1.42      | 22.6±1.70       | 22.6±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±0.27                         | 0.41±0.40        | 4.45±4.6        | 3.07±2.2       | 5.57±4.1       | 5.64±3.9        | 7.11±0.7       |               | 0.0743      |
| Conductivity (\( \mu \text{scm} \)) | 1404.0±1239 | 878.9±290       | 880.8±305       | 926.1±297      | 616.1±124      | 128.2±23        | 240.3±136      |               | 0.0305      |
| NO\textsubscript{3}-N (µg/L) | 43.31±3.41                         | 19.1±14.4        | 19.3±16.2       | 30.5±23.1      | 35.4±27.2      | 79.2±110.9      | 135.8±198.2    |               | 0.5012      |
| NO\textsubscript{2}-N (µg/L) | 67.08±4.58                         | 58.0±41.0        | 31.1±8.5        | 44.7±22.9      | 45.7±27.7      | 110.0±89.5      | 192.7±259.7    |               | 0.3932      |
| NH\textsubscript{4}-N (µg/L) | 25.93±14.54                        | 674.0±511.1      | 1090.0±639.9    | 987.1±542.8    | 776.1±418.3    | 813.9±727.2     | 605.1±459.0    |               | 0.7403      |
| SRP (µg/L)   | 1121.0±240.9                      | 725.4±80.9       | 1002.1±396.3    | 803.6±551.5    | 479.9±334.6    | 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    | 619.53±609.2   |               | 0.8232      |
| TN (µg/L)    | 800.1±730.4                       | 409.0±221.1      | 1280.7±875.9    | 1231.3±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 nitrate and nitrite-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 nitrate and nitrite-nitrogen of 35.45 µg/L ± 27.2 and 45.73 µg/L ± 27.7 SD respectively. The measured nitrate-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 measured 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
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 (°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  |
| NO₃-N (mg/L) | 107.4±167.0 | 47.2±19.5   | 17.5±11.2   | 35.3±26.8   | 0.2495  |
| NO₂-N (mg/L) | 131.3±122.5 | 78.5±36.4   | 43.5±21.4   | 60.5±31.8   | 0.4839  |
| NH₄-N (mg/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 | 437.4±48.2  | 596.1±635.1 | 644.7±484.8 | 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 | 1233.4±605.6 | 0.0013  |

3.2.1 Temperature
Month of August had the highest mean temperature of 25.23 °C ± 2.99 SD, followed by September with mean of 24.76 °C ± 1.91 SD and November recorded a mean of 23.83 °C ± 2.17 SD. The month of December had the lowest mean temperature of 23.44 °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 4.73 ± 3.5 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 lower by between 2.132 and 3.974 than that of December. For September, the mean pH was lower by between 2.593 and 4.435 than that of December. Similarly, the mean pH for November was lower 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 lower by between 2.558 mg/L and 7.489 mg/L than that of September. For September, the mean DO was higher by between 1.093 mg/L and 6.024 mg/L than that of November. Similarly, the mean DO for September was higher by between 0.416 mg/L and 5.347 mg/L than that of December.

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).

3.2.4 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 had the highest mean of 811.2 µg/L ± 663.1 SD. 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 ± 218 SD respectively (Table 2). Single factor ANOVA showed that TP was not statistically significant between the sampling months (F (3, 24) = 1.3722; p = 0.9964).

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The month of August recorded the highest mean of TN of 3147.5 µg/L ± 904 SD, followed by the month of December recorded mean of 1407.5 µg/L ± 218 SD respectively (Table 2). Single factor ANOVA showed that TN was not 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 lower 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 higher by between 383.7 µg/L and 1374.6 µg/L than that of December. The mean TN for November was higher 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, Zygmematophyceae, and Dinophyceae represented by 10 (8%), 9 (7%), and 4 (3%) species respectively.

| Chlorophyceae | Cyanophyceae | Bacillariophyceae |
|--------------|--------------|------------------|
| Ankistrodesmus falcatus | Anabaena circinalis | Amphora ovata |
| Botryococcus braunii | Anabaena flor-aquae | Amphora sp. |
| Coelastrum microporum | Anabaena limnetica | Aulacoseira ambiguca |
| Coelomoros merostoides | Aphanocapsa pularvaa | Aulacoseira ambigua |
| Coelomoros reguraris | Aphanocapsa rivularis | Aulacoseira Schroidera |
| Coelomoros vestitus | Aphanathece sp | Chodatella longiseta |
| Crucigenia menenghiana | Chodatella longiseta | Chodatella sp. |
| Crucigenia sp | Chrococccus dispersus | Cyclotella kutzinghiana |
| Dictyosphaerium sp | Chrococccus limnetica | Cyclotella ocellata |
| Kirchnella contorta | Chrococccus limnetica | Cymbella cistula |
| Kirchnella lunaris | Chrococccus turgidus | Diatoma elongatum |
| Kirchneriella schimide | Coelomoros merostoiide | Diatoma hemiale |
| Monoraphidium sp | Coelomoros vestitoz | Euglenophylandia vivids |
| Oocystis nalgeli | Cylindrospermopis africana | Eunotia flexuosas |
| Oocystis parva | Merismopedia punctata | Flagariaria athiopicas |
| Oscillatoria gemirata | Merismopedia tennassima | Flagariaria construa |
| Oscillatoria tenuis | Microcystis aeruginosa | Flagariaria crotonensis |
| Pediatium boryanum | Microcystis flə-aquae | Navicula gastra |
| Pediatium duplex | Microcystis wasenbergii | Navicula granatum |
| Pediatium tetra | Oscillatoria tangauiykae | Navicula pulula |
| Rhabdium braunii | Oscillatoria tenuis | Navicula salicina |
| Scenedesmus curvatus | Planktolyngbya talingii | Navicula simplex |
| Scenedesmus quadricuda | Planktolyngbya circumcreta | Navicula sp. |
| Scenedesmus acuminatus | Planktolyngbya limnetica | Nitzschia lacustris |
| Scenedesmus maximus | Planktolyngbya talingii | Nitzschia palea |
| Scenedesmus obliquus | Pseudo-anabaena tanganyikae | Nitzschia recta |
| Scenedesmus quadricuda | Romenia ankensis | Nitzschia sub acicularis |
| Scenedesmus quadricuda | Romenia elegans | Pinnularia subcepiata |
| Schrodieria setgera | Spirulina princeps | Stephanoiscus astrea |
| Surillette elegans | Spirulina sp. | Stephanodiscus sp. |
| Tetraedron arthromisforme | Surillette affinis | Surillette affinis |
| Tetraedron inflatum | Euglenophyceae | Surillette sp. |
| Tetraedron triangulare | Euglena acus | Surillette tenera |
| Tetraedron trigonum | Euglena Virids | Syndra cunningtonii |
| Dinophytaeae | Euglenophylandia acus | Synedra abna |
| Ceratium branchyeceros | Euglenophylandia virids | Tubellaria sp. |
| Glenodinium permardii | Phacus longicauda | Zygmematophyceae |
| Glenoridinum pulvasistoiz | Phacus pleunortecte | Closterium navicula |
| Glenoridinum permardii | Phacus sp | Cosmarium lauderni |
| Strombomonas sp | Cosmarium lunell |
| Trachelomonas armata | Cosmarium menenghiana |
| Trachelomonas volvocina | Cosmarium paradoxum |
| Crucigenia menenghiana | ~ 303 ~
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

| Taxa (s)       | Influent | Anaerobic | Facultative | Tertiary | Effluent | River point 1 | River point 2 |
|----------------|----------|-----------|-------------|----------|----------|---------------|---------------|
| 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         |

3.5 Phytoplankton biomass and distribution
During the study period, the total phytoplankton biovolume of 385.24 mm$^3$/L was recorded with the family Euglenophyceae contributing to 35.864% of the total phytoplankton biovolume (Table 5). This was followed by the family Dinophytales 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                   |
| Dinophytales    | 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 Dinophytales 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 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).
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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