Periphyton as Inorganic Pollution Indicators in Nyangores Tributary of the Mara River in Kenya

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Abstract: The aim of this study was to investigate the use of attached algae also known as periphyton as indicators of inorganic pollution in Nyangores tributary of Mara River in Kenya. The river suffers impacts of agricultural pollutants in its upper course due to the intensive farming activities in this region coupled with other anthropogenic activities which result into the production of various pollutants that finally find their way into this river. The river was sampled twice a month from February 2012 to May 2012, at eight sites in which the data on nutrients and periphyton community structure and biomass were collected. Simultaneously, physical and chemical variables such as water temperature, conductivity, discharge, total suspended solids, pH, dissolved oxygen, ammonium, nitrate, nitrite, soluble reactive phosphorus, total phosphorus were measured. In order to interpret the influence of the environmental on the periphyton characteristics, two-way ANOVA was used. The data collected was statistically analyzed using JMP version 10 (product of SAS Inc: - Statistical Analysis System) for significant differences between the periphyton community structures with temporal nutrient variation as well as comparison of different physical and chemical parameters between sampling sites in different months. The findings from this study showed that nutrients had a strong correlation with periphyton community structure.

Keywords: Anthropogenic, biomass, catchment, community structures, temporal

INTRODUCTION

In-stream nutrient concentrations have been correlated to human activity in many river basins (Gergel et al., 2002). As ambient nutrient concentrations increase, stream physical characteristics such as light availability and temperature become increasingly important in governing algal periphyton growth (Morgan et al., 2006). Periphyton biomass accumulation and the development of nuisance algae have been shown to be strongly associated with nutrient enrichment in streams (Lohman et al., 1992). Many studies have linked ambient nutrient concentrations to periphyton biomass (Tank and Dodds, 2003; Stevenson et al., 2008) and shown that both N and P can influence their growth (Biggs, 2000).

Many studies have documented effects of nutrients on periphyton (Biggs, 2000), but the data in regional studies are limited to predict effects of specific nutrient on periphyton community within a river. In addition, many factors such as light intensity and duration could affect periphyton-nutrient relationships in streams. This may occur within a region and among regions with different climate, geology and water chemistry accounting for spatial and temporal variability in nutrient concentrations (Biggs, 2000).

Measuring the variables that govern periphyton biomass requires consideration of ambient conditions such as temperature, pH, dissolved oxygen, electrical conductivity, discharge, light availability and nutrient concentrations (Hill and Knight, 1988). These variables have been measured and correlated individually to algal periphyton growth (Stevenson, 1996) hence considered essential for growth and development of algal periphyton. Nutrient and light availability have been documented to limit periphyton growth in small streams (Hill and Fanta, 2008). In order to understand these relationships, it is necessary to measure levels of nutrient availability in situ across a gradient of selected anthropogenic conditions while accounting for variations in algal biomass accumulation due to secondary factors such as light availability, temperature, discharge, substrate and losses due to scour.

MATERIALS AND METHODS

Study site: The study was carried out in Nyangores, a tributary of Mara River, located in the eastern arm of the Great Rift Valley in Kenya, at an altitude of 1759 m above sea level and a geographical location of 00° 22′S, 36° 05′E (Fig. 1). Sampling sites were chosen based on land-use in the adjacent areas. The highest station among the seven chosen stations was Kiptagich and the lowest was the confluence between Amala and Nyangoes. The sampling stations were clustered...
Fig. 1: Mara river basin showing nyangoretributary (adopted from Mati et al., 2005)

Table 1: Location of the various sampling sites in the study

<table>
<thead>
<tr>
<th>Stations</th>
<th>Local name</th>
<th>Location</th>
<th>Activities</th>
<th>Clustered sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Kiptagich</td>
<td>S 00°71.33', E 035°51.23'</td>
<td>Forested, Wildlife</td>
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</tr>
<tr>
<td>S2</td>
<td>Ainapng’etunyek</td>
<td>S 00°72.47', E 035°43.78'</td>
<td>Forested, Wildlife, Tea plantation</td>
<td>Forested</td>
</tr>
<tr>
<td>S3</td>
<td>Silibwet</td>
<td>S 00°73.78', E 035°36.23'</td>
<td>Tea growing, Maize cultivation</td>
<td>Farmland</td>
</tr>
<tr>
<td>S4</td>
<td>Tenwek</td>
<td>S 00°74.64', E 035°36.49'</td>
<td>Sewage disposal, Maize cultivation</td>
<td>Farmland</td>
</tr>
<tr>
<td>S5</td>
<td>Raiya</td>
<td>S 00°77.52', E 035°35.14'</td>
<td>Washing, fishing, Maize cultivation</td>
<td>Farmland</td>
</tr>
<tr>
<td>S6</td>
<td>Bomet prison</td>
<td>S 00°79.58', E 035°33.85'</td>
<td>Dumping of wastes, cattle grazing</td>
<td>Rangeland</td>
</tr>
<tr>
<td>S7</td>
<td>Olbutyo</td>
<td>S 00°85.66', E 035°27.99'</td>
<td>Pastoralism, washing of vehicles</td>
<td>Rangeland</td>
</tr>
<tr>
<td>S8</td>
<td>Confluence</td>
<td>S 00°86.54', E 035°27.99'</td>
<td>Pastoralism, charcoal burning</td>
<td>Rangeland</td>
</tr>
</tbody>
</table>

together based on the economic activities within the area. Three major sites were adopted. These were forested, farmland and rangeland sites (Table 1).

Collection of samples: Prior to the field sampling, a reconnaissance survey was carried out in order to select the sampling stations based on the dominant land use.
such as forest, crop farming and pastoralism. Eight sampling stations were selected on the Nyangores tributary (Table 1). The sampling stations were selected about 900 m to 10 km from each other along the stretch of the river in order to avoid point sources of pollution that could adversely influence the results of the study (Furse et al., 2006). Sampling was done fortnightly for a period of four months.

**Physical and chemical variables:** Selected physical and chemical properties including dissolved oxygen concentration and saturation, temperature, conductivity and pH of the stream were measured in situ using the Multi meters probes (HACH HQ 4 d and HACH Eco 40 °Canada). The probes were always calibrated before use.

**Nutrient analyses:** Water samples were collected using 500 mL plastic bottles that were previously acid-washed in the laboratory. Before each sample collection, the sample bottles were rinsed with the river water at each sampling point. The water samples collected were kept in a cool box and preserved in ice after which they were transported to Egerton University laboratory for analysis. In the laboratory nutrient analyses were done according to the standard methods as given by the American Public Health Association (APHA, 2005). The soluble nutrients, including SRP, NO3-N, NO2-N and NH4-N were analysed from filtered water samples, while unfiltered water sample was used for TP analysis after persulfate digestion. Total Phosphorus (TP) and Soluble Reactive Phosphorous (SRP) were analyzed using the ascorbic acid method with absorbance read at a wavelength of 885 nm. Nitrate-nitrogen (NO3-N) was analysed using the salicylate method with the spectrophotometric absorbance read at a wavelength of 420 nm. Nitrite-nitrogen (NO2-N) concentration was determined based on the reaction between sulfanilamide and N-naphthyl-(1)-ethylenediamin-dihydrochloride. The intensity of colour formed was read at 543 nm. Ammonium-nitrogen (NH4-N) was analyzed through the reaction between sodium salicylate and hypochlorid solutions with the spectrophotometric absorbance of the treated sample being read at a wavelength of 655 nm. The absorbance values read were used to work out the concentration using equations generated from the standard calibration curves made for each of the nutrient species.

**Total suspended solids:** The total suspended solid in the water was determined gravimetrically. Water sample of volume 250 mL was filtered through an oven-dried, pre-weighed GF/C Whatman glass-fiber filters (0.45 µm pore size with 47 mm diameter) and oven-dried at 103 to 105°C to constant dry weight. Weighing was done using SCALTEC®SPB31 analytical balance. Calculation of the concentration of total suspended solids in the sample was done using the following equation:

\[
\text{TSS (mg L}^{-1}) = \frac{(A-B)}{V} \times 1000
\]

where,

- \( A \) = Sample and filter weight, mg
- \( B \) = Filter weight, mg
- \( V \) = Sample volume, mL

**Periphyton sampling:** Periphyton community structure and biomass was determined from artificial wooden substrates introduced in the water on which the organisms were allowed to develop onto. Triplicates of wooden substrates measuring 12 cm by 75 cm were placed about 100 m apart in the different sampling stations. These were left for colonization by the periphyton. The periphytons were harvested after two weeks and subsequent harvesting done bi-weekly for four months. Periphyton was removed from the substrate by scraping of the surface substrates measuring 12 cm by 75 cm. Brushing was then done to collect periphyton into a 50 mL plastic container with a funnel placed at the top of the container. The substrates were rinsed with distilled water to collect any remaining periphyton into the 50 mL plastic container. The collected samples were preserved in 4% formalin and then transported to Egerton University for further processing and analysis.

**Algal periphyton identification:** The collected periphyton samples were analysed for community composition by taking 1ml of well shaken sample and placing on the counting chamber of the inverted microscope (Motic®AE31 series). Periphyton species were identified through observation under the microscope at the magnifications of x 200 and x 400 and using identification keys by Prescott (1964), John et al. (2002) and Wehr and Sheath (2003).

**Algal periphyton enumeration and biovolume analysis:** The identified species were enumerated by counting all individuals, including single cells, colonies and filaments on a cell-by-cell basis using a 3 mL Sedgwick-Rafter counting chamber. To estimate the taxa biovolumes, the individual cells were taken as the unit of measurement for each taxon. The cell shapes of each taxon were approximated to the standard geometric shapes such as spheres, cuboid or cylinders and their standard formulae used to calculate biovolume according to Hildebrand et al. (1999) and Wetzel and Likens (1991). The measurements of the cell dimensions such as the lengths and widths were made using a calibrated stage micrometer and the ocular grids in the microscope. Mean cell volumes were obtained by averaging the volumes of 30 individual cells. The total biovolume for each species was calculated from the product of abundance or cell numbers and the mean biovolume of each species. The biovolumes determined were worked out per unit area of the substrate where the samples were collected.
The increase in conductivity was noted from February to May among all the sites. In March there was significant difference in electrical conductivity in forested site when compared to the farmland and rangeland sites (Tukey’s HSD test, p<0.05).

Dissolved Oxygen (DO) concentration generally decreased downstream with the lowest values recorded in the rangeland zones (6.13±0.09 mg/L) and higher values being recorded in the forested upper zone (8.09±0.11 mg/L) (Table 2). The mean DO concentration for each site was 7.40, 7.34 and 7.28 mg/L for forested, farmland and rangeland sites, respectively. During the months of February, March and April, there was a significant difference in DO concentrations only at the forested sites but the farmland and rangeland sites were similar (Tukey’s HSD test, p<0.05). However, in May all sites had statistically different concentrations of dissolved oxygen (Tukey’s HSD test, p<0.05).

A temporal trend of increase in the concentration of suspended solids was observed with the lowest value of 6.86±0.22 mg/L recorded in February in forested site and the highest values 351.77±1.4 mg/L recorded in May in the rangeland site (Table 2). The mean TSS concentrations for each site were 41.02, 99.26 and 351.77±1.4 mg/L for forested, farmland and rangeland sites, respectively showing a spatial trend of increase downstream. During the months of February, March and April, there was no significant difference in TSS concentrations only at the forested sites but the farmland and rangeland sites were similar (Tukey’s HSD test, p<0.05). However, in March the TSS concentration at forested site was significantly different from the other two sites (Tukey’s HSD test, p<0.05).

Spatial-temporal changes in nutrients: The highest levels of NH4-N were recorded in May at farmland site (184.23±5.72 µg/L). The concentration dropped from 92.67 µg/L in March to 80.33 µg/L in April in farmland.
sites. There was significant differences in the amount of NH$_4$-N concentration between the sites (Two-way ANOVA, $F_{2, 20} = 236.44$, $p<0.05$). NH$_4$-N concentrations showed a trend of gradual increase from the upper reaches in the forested area to the rangeland downstream (Fig. 2).

The highest concentration of NO$_2$-N (34.85±4.05 µg/L) was recorded in April at rangeland site. The lowest concentration was recorded in March (1.53±0.02 µg/L) at the forested sites (Fig. 2). NO$_2$-N levels fluctuated in all the sites but showed significant (Two-way ANOVA, $F_{2, 20} = 278.73$, $p<0.05$) differences between all the sites. This temporal fluctuation was especially significant at the rangeland site except between the months of March and May (Tukey’s HSD test, $p<0.05$).

The highest NO$_3$-N concentration was recorded in the rangeland site (653.86±35.34 µg/L) in May while the lowest concentration was recorded at the forest site (23.31±2.16 µg/L in February (Fig. 2). Multiple pairwise comparison showed that there were significant differences in the NO$_3$-N concentrations between all the sites (Two-way ANOVA, $F_{2, 20} = 1183.45$, $p<0.05$). A trend of increase in NO$_3$-N concentrations was observed from forested site upstream to the rangeland downstream. In the farmland site between months comparisons of NO$_3$-N concentrations were all significant. In the rangeland site there was no significant difference (Tukey’s HSD test, $p<0.05$) of NO$_3$-N concentrations between the months of February and March.

The lowest concentrations of SRP were recorded in February and March at the forested site (Fig. 2). SRP concentrations increased remarkably in April and May with the highest concentration being recorded in May (119.91±3.39 µg/L) at rangeland site. There were significant spatial SRP concentration differences between all sites (Two-way ANOVA, $F_{2, 20} = 880.49$, $p<0.05$). Temporal change in SRP concentrations in the farmland site was not significantly different (Tukey’s HSD test, $p>0.05$) between the months of February and March while the rangeland sites showed significant differences in all the months during the study (Tukey’s HSD test, $p<0.05$).

A trend of spatial increase in TP downstream was recorded in all the three months with the highest concentrations being recorded in Rangeland (246.11±24.31 µg/L) in the Month of May (Fig. 2). The concentrations varied significantly (Two-way ANOVA, $F_{2, 20} = 227.32$, $p<0.05$) between all the sites. In farmland site there was no significant difference in TP concentrations between the months of February and March (Tukey’s HSD test, $p<0.05$).

Algal periphyton community structure in nyangores tributary: Diatoms (Bacillariophytes), the green algae (Chlorophytes) and the blue-green algae (Cyanophytes) dominated the algal periphyton community structure throughout the study period. The major taxa identified included the diatoms such as:- Surirella sp., Fragilaria sp., Navicula sp., Nitzschia sp., Gomphonema sp. and Cymbella sp., blue-green algae/Cyanophytes such as Limnothrix sp. and Lyngbya sp. and green algae Closterium sp. Most of these species were recorded in all the stations throughout the study period except Limnothrix sp. which was absent in the forested site and Lyngbya sp. which was absent in the rangeland site during the month of May (Table 3).
Table 3: Temporal composition of periphyton species at each sampling site in Nyangores from February to May 2012 (+ or − denote presence or absence of species)

<table>
<thead>
<tr>
<th>Month</th>
<th>Site</th>
<th>Surirella sp</th>
<th>Fragilaria sp</th>
<th>Navicula sp</th>
<th>Limnothrix sp</th>
<th>Nitzschia sp</th>
<th>Lyngbya sp</th>
<th>Gomphonema</th>
<th>Closterium sp</th>
<th>Cymbella sp</th>
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<tbody>
<tr>
<td>February</td>
<td>Forested</td>
<td>+</td>
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<td>+</td>
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<td>Farmland</td>
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<td>Rangeland</td>
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<tr>
<td>March</td>
<td>Forested</td>
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<td>Farmland</td>
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<td>April</td>
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Fig. 3: The percentage biovolume of major algal periphyton groups in Nyangores tributary from February and May 2012

Algal periphyton percentage biovolume: All the genera of algal periphyton grouped together gave three major divisions as shown in Fig. 3. The most dominant taxa of periphyton in terms of biovolume was the Bacillariophytes, followed by Cyanophytes and then the Chlorophytes.

Spatio-temporal variations in algal periphyton biomass: The biomass (mm$^3$/cm$^2$) of individual taxa varied but was observed to generally increase from February to April with a decline occurring in May. The biomass of *Closterium* sp. was recorded to be higher (1190 mm$^3$/cm$^2$) in April at the forested site of Nyangores tributary but lowest in rangeland site (218 mm$^3$/cm$^2$) (Fig. 3). There were significant differences in *Closterium* sp. biomass between all the sites (Two-way ANOVA, $F_{2, 20} = 740.39$, $p<0.05$) and between sampling periods (Two-way ANOVA, $F_{3, 20} = 179.53$, $p<0.05$). Statistical analysis showed that there was effect of spatio-temporal interaction of month and site on the biomass of *Closterium* sp. (Two-way ANOVA, $F_{6, 20} = 36.42$, $p<0.05$) which increased from February to April but declined in May in all the sites. In February and March the biomass of *Cymbella* sp. was similar between forested and rangeland sites but significantly different in farmland site (Tukey’s HSD test, $p<0.05$). However, in May the biomass of *Cymbella* sp. was significantly different among the three sites (Tukey’s HSD test, $p<0.05$).

The biomass of *Gomphonema* sp. was highest in April (370 mm$^3$/cm$^2$) in the farmland site but lowest in February (58 mm$^3$/cm$^2$) at forested site (Fig. 3). Spatial comparison of *Gomphonema* sp. biomass showed that there were significant differences amongst all the sites (Two-way ANOVA, $F_{2, 20} = 334.77$, $p<0.05$) and between sampling periods (Two-way ANOVA, $F_{3, 20} = 64.63$, $p<0.05$). In addition statistical analysis indicated that there was effect of spatio-temporal interaction of month and site on the *Gomphonema* sp. biomass (Two-way ANOVA, $F_{6, 20} = 42.37$, $p<0.05$) which increased from February to April but declined in May in all the sites. Temporal comparison of *Gomphonema* sp. biomass in February revealed significant differences in forested site but farmland and rangeland sites were similar (Tukey’s HSD test, $p<0.05$). However, *Gomphonema* sp. biomass during the subsequent months of March, April and May at the farmland site were significantly different but similar in forested and rangeland sites (Tukey’s HSD test, $p<0.05$).
Fig. 4: Temporal variations in biomass of *Gomphonema*, *Lyngbya*, *Limnothrix*, *Closterium* and *Cymbella* spp from February to May 2012 at different sites along Nyangores.

*Lyngbya* sp. biomass was highest in April at the farmland site (1500 mm$^3$/cm$^2$) (Fig. 4). Lowest biomass of *Lyngbya* sp. was recorded in the forested site across all the months. The biomass were significantly different (Two-way ANOVA, $F_{(2, 20)} = 217.81$, $p<0.05$) in all the compared sites and between the sampling periods (Two-way ANOVA, $F_{(3, 20)} = 37.47$, $p<0.05$). Spatio-temporal interaction of month and site on the biomass of *Lyngbya* sp. was equally significantly different (Two-way ANOVA, $F_{(6, 20)} = 10.11$, $p<0.05$) with its biomass increasing from February to April but declining in May in all the sites. In the months of February, March, April and May, *Lyngbya* sp. biomass was significantly different between all the three sites (Tukey’s HSD test, $p<0.05$).

*Limnothrix* sp. biomass showed great fluctuations with the highest biomass being recorded in April (429 mm$^3$/cm$^2$) in the rangeland site (Fig. 4). There was significant difference in *Limnothrix* sp. biomass between the sites (Two-way ANOVA, $F_{(2, 20)} = 3.77$, $p<0.05$). However statistical analysis between the sampling periods was insignificant (Two-way ANOVA, $F_{(3, 20)} = 0.62$, $p<0.05$). In addition there was no significant difference of the effect of spatio-temporal interaction of month and site on the biomass of *Limnothrix* sp. (Two-way ANOVA, $F_{(6, 20)} = 0.68$, $p<0.05$) which increased from February to April but declined in May in all the farmland and rangeland sites. During the months of February, March, April and May *Limnothrix* sp. biomass were similar in forested and rangeland sites but significantly different in farmland site (Tukey’s HSD test, $p<0.05$).

The highest biomass of *Navicula* sp. was observed in the forest site (50,200 mm$^3$/cm$^2$) in March (Fig. 5). The biomass of *Navicula* sp. was significantly different (Two-way ANOVA, $F_{(2, 20)} = 1682.71$, $p<0.05$) between all the sites and between sampling periods (Two-way ANOVA, $F_{(3, 20)} = 76.68$, $p<0.05$). Statistical analysis also revealed that there was effect of spatio-temporal interaction of month and site on the biomass of *Navicula* sp. (Two-way ANOVA, $F_{(6, 20)} = 17.45$, $p<0.05$) which increased from February to March and a decline noted from April to May in all the three sites. In the months of February, March, April and May the biomass of *Navicula* sp. were similar in forested and farmland sites but significantly different in the rangeland site (Tukey’s HSD test, $p<0.05$).

*Nitzschia* sp. biomass was highest in March and April (>17,000 mm$^3$/cm$^2$) at the upper reaches in the forest sites (Fig. 5) with lower values recorded at the downstream sites. Spatial biomass comparison showed that *Nitzschia* sp. biomass variations were significant (Two-way ANOVA, $F_{(2, 20)} = 76.61$, $p<0.05$) between all sites and between sampling periods (Two-way ANOVA, $F_{(3, 20)} = 3.65$, $p<0.05$). Statistical analysis revealed that there was effect of spatio-temporal interaction of month and site on the biomass of *Nitzschia* sp. (Two-way ANOVA, $F_{(6, 20)} = 1.34$, $p<0.05$) which increased from February to April but declined in May in all the sites. During the month of February *Nitzschia* sp. biomass were similar in forested, farmland and rangeland sites (Tukey’s HSD test, $p<0.05$). However in March, April and May *Nitzschia* sp. biomass was only similar between forested and farmland sites but significantly different in rangeland site (Tukey’s HSD test, $p<0.05$).

The highest biomass of *Navicula* sp. was observed in the forest site (50,200 mm$^3$/cm$^2$) in March (Fig. 5). The biomass of *Navicula* sp. was significantly different (Two-way ANOVA, $F_{(2, 20)} = 1682.71$, $p<0.05$) between all the sites and between sampling periods (Two-way ANOVA, $F_{(3, 20)} = 76.68$, $p<0.05$). Statistical analysis also revealed that there was effect of spatio-temporal interaction of month and site on the biomass of *Navicula* sp. (Two-way ANOVA, $F_{(6, 20)} = 17.45$, $p<0.05$) which increased from February to March and a decline noted from April to May in all the three sites. In the months of February, March, April and May the biomass of *Navicula* sp. were similar in forested and farmland sites but significantly different in the rangeland site (Tukey’s HSD test, $p<0.05$).

*Nitzschia* sp. biomass was highest in March and April (>17,000 mm$^3$/cm$^2$) at the upper reaches in the forest sites (Fig. 5) with lower values recorded at the downstream sites. Spatial biomass comparison showed that *Nitzschia* sp. biomass variations were significant (Two-way ANOVA, $F_{(2, 20)} = 76.61$, $p<0.05$) between all sites and between sampling periods (Two-way ANOVA, $F_{(3, 20)} = 3.65$, $p<0.05$). Statistical analysis revealed that there was effect of spatio-temporal interaction of month and site on the biomass of *Nitzschia* sp. (Two-way ANOVA, $F_{(6, 20)} = 1.34$, $p<0.05$) which increased from February to April but declined in May in all the sites. During the month of February *Nitzschia* sp. biomass were similar in forested, farmland and rangeland sites (Tukey’s HSD test, $p<0.05$). However in March, April and May *Nitzschia* sp. biomass was only similar between forested and farmland sites but significantly different in rangeland site (Tukey’s HSD test, $p<0.05$).
The highest biomass of *Surirrella* sp. was recorded in the month of May (9,500 mm$^3$/cm$^2$) at the forested site (Fig. 5). Comparison of *Surirrella* sp. biomass showed significant difference between the sites (Two-way ANOVA, $F_{(2, 20)} = 3016.70$, $p<0.05$) and between sampling periods (Two-way ANOVA, $F_{(3, 20)} = 481.00$, $p<0.05$). Statistical analysis revealed that there was effect of spatio-temporal interaction of month and site on the biomass of *Surirrella* sp. (Two-way ANOVA, $F_{(6, 20)} = 10.78$, $p<0.05$) which increased from February to April but declined in May in all the sites. In February the biomass of *Surirrella* sp. was similar between farmland and rangeland sites but significantly different in forested site (Tukey’s HSD test, $p<0.05$). However, during the subsequent months of March, April and May the biomass of *Surirrella* sp. was significantly different in all the sites (Tukey’s HSD test, $p<0.05$).

*Fragilaria* sp. biomass reached its peak in April at the forested site while the lowest biomass was recorded in May at the rangeland site (Fig. 6). The biomass of *Fragilaria* sp. showed significant difference between sites (Two-way ANOVA, $F_{(2, 20)} = 20360.38$, $p<0.05$) and between sampling periods (Two-way ANOVA, $F_{(3, 20)} = 249.56$, $p<0.05$). In addition statistical analysis showed that there was effect of spatio-temporal interaction of month and site on the biomass of *Fragilaria* sp. (Two-way ANOVA, $F_{(6, 20)} = 188.63$) which increased from February to April but declined in
May in all the sites. In all the months Fragilaria sp. biomass was similar in the forested and farmland site but significantly different in the rangeland site.

**DISCUSSION**

**Physical and chemical characteristics:** Water temperature had slight variation among the three sites. This could have been attributed to the opening of the canopy from the forest to rangeland sites. Environmental monitoring studies in Southern Brazil (Lobo et al., 1996; Oliveira et al., 2001; Lobo et al., 2004; Salomoni et al., 2006) showed that periphyton community composition and biomass in lotic ecosystems are a result of the interaction of physicochemical variables such as temperature as well as the process of inorganic contamination. This observation agrees with this research findings that found that Limnothrix and Lyngbya spp were absent in the periphyton communities within the forest but became dominant in the farmland and rangeland sites where environmental conditions had changed markedly. The relatively slight increase in temperatures at rangeland site were caused by direct heating of the river channel by the sun and heat exchange with the atmospheric air due to the opening of canopy downstream (Mathooko et al., 2009). The relatively low temperatures in the forest sites can be attributed to the cooling effects rendered by the dense forest canopy and higher altitude. This observation agrees with the studies by Swift (1983) who found forests to influence the temperature regimes of rivers and their periphyton community structure.

The increase in electrical conductivity observed from February to May between farmland and Rangeland sites could be attributed to the increase in loading of sediments rich in ions from the catchment into the river as it flows downstream. Electrical conductivity was noted to increase from forested to rangeland site, a characteristic attributed to the increased deposition of ions as a result of increased cumulative effects of catchment runoffs downstream (Mathooko, 2001). The results of this study indicated a positive correlation between electrical conductivity and discharge, an observation supported by Kutty (1987). The implication is that as discharge increases, conductivity increases due to increased ion concentrations in the water column.

Oxygen concentration in Nyangores was temporally and spatially more variable due to water turbulence and mixing with atmospheric air (Jacobson, 2003). High Dissolved Oxygen (DO) was recorded at the forested reaches located upstream presumably due to high turbulence which enhances mixing of atmospheric air with the river water. Generally upstream of rivers have high riffle sections and therefore experience eddying currents that enhance dissolution of oxygen in the water (ANZECC, 1997). The relatively low oxygen concentrations recorded in farmland and rangeland sites could be attributed to reduced turbulence as the river becomes gentler. Similarly, relatively high water temperatures at rangeland site compared to forested site contributed to the low oxygen concentration in the same site since increased water temperatures reduce oxygen solubility.

Total Suspended Solids (TSS) content at Nyangores tributary showed significant variations in most of the sites at different months which indicate changes in rates of sediment loading from upstream at different times, mainly associated with rainfall patterns with the observed high values in May coinciding with the rainy season around this time. High suspended solids contents observed downstream was attributed to the cumulative effects of surface runoffs coupled with the poor riparian vegetation cover due to clearance of vegetation along the river for farmland and charcoal burning downstream. The type of farming involving keeping of large number of domestic animals, mainly cattle and sheep around this area of the rangeland also caused overgrazing that exposed the soil layers to soil erosion in this zone. This observation is supported by studies carried out by Johnson et al. (2005) on various rivers of Southwest Ireland, whose results showed significant differences in suspended solids content due to changes in vegetation cover of the riparian zones along the rivers. Hondzo and Wang (2002) pointed that increased TSS mask the growth of periphyton due to light inhibition.

Generally pH range in this river is around neutral range (6.0 to 8.3) a condition always attributed to the nature of the soils and geology of the catchment (Bailey and Busulwa, 1996). In addition pH values in rivers are dependent on anthropogenic inputs and bedrock properties (Yang et al., 2010) and it influences growth and composition of aquatic biota (Lepori et al/September 12, 2013 and consequently had little impact on algal periphyton. The slight increase in pH observed at the rangeland site in the month of May could have been attributed to use of fertilizers in the catchment and subsequent loading to aquatic environment through surface runoff into the river.

**Relationship between algal periphyton community structure and nutrient concentrations:** Nutrients availability in aquatic systems is a major factor influencing growth of the aquatic fauna with high biomass of aquatic flora being associated with high nutrient content and vice versa (Dodds, 2003). All plants require phosphorus and nitrogen as primary nutrients essential for their growth. Both nitrogen and phosphorus contents in the Nyangores tributary were moderate in concentration and there was an increase in
their concentration with increase in discharge downstream. According to studies by Kim et al. (1992) nutrients concentrations vary diurnally with microbial metabolism; daily with weather related hydrologic factors and with increasing biomass and nutrient uptake during periphyton community development after storms; and seasonally with human activities and metabolism of terrestrial vegetation in watersheds. The farmland and rangeland sites were highly disturbed with a lot of clearance of riparian vegetation, which facilitated runoff that wash nutrients into Nyangores tributary. Contribution of agricultural fertilizers and animal wastes from the catchment cannot be ignored as it could enhance nutrients concentrations in the adjacent farmland and rangeland sites.

Periphyton requires specific optimum environmental conditions such as moderate temperature, DO concentration, electrical conductivity and pH for rapid growth and reproduction (Wetzel and Likens, 1991). Changes in these conditions influence them either directly or indirectly through their growth and biomass. Dodds (2003) showed that variation in periphyton biomass among streams is related to nutrient concentrations. Biggs (2000) related periphyton biomass to soluble nutrients such as SRP and NH₄-N. The increased amounts of nutrients coupled with slight increase in discharge could explain the significant increase in biomass of Surirrella sp., Fragilaria sp., Limnothrix sp., Lyngbya sp. and Cymbella sp. at the rangeland site. However with increased nutrients as a result of high discharge, the biomass of Closterium sp. significantly declined at the rangeland site. Some of the periphyton observed in Nyangores are shown in Plate 1. This could be attributed to the thickness of algal periphyton mat due to the growth of Surirrella sp., Fragilaria sp., Limnothrix sp., Lyngbya sp. and Cymbella sp. at the surface thereby affecting nutrient availability to closterium sp. which occurred in lower layers of the algal periphytic mat. Such a feature was recorded by Stevenson and Glover (1993) who noted that Closterium tend to grow at the lower layers of periphyton mats from which they may not efficiently get adequate nutrients dissolved in the water. Pringe (1990) found that algal taxa in the upper layers of periphyton appeared to interfere with inorganic nutrient procurement by understorey sessile taxa such as Closterium sp. Thus nutrients may become limiting within periphyton mats even when nutrients supply in the water column is constant. A similar trend of periphyton growth and decrease in biomass was reported by Francoeur (2001) in Michigan and Kentucky streams where extensive growths of periphyton in high nutrient streams was due to less frequent flood disturbances.

The occurrence of high biomass of some algal periphyton species such as Fragilaria sp. in low nutrients conditions in some of the sites in Nyangores tributary could be attributed to their fast growth rates and abilities to exploit resources more effectively than others which lead to their dominance in the periphyton community structure (Stevenson and Glover, 1993). The biomasses of Navicula sp. and Limnothrix sp. did not show significant correlation with nutrient concentration. Such species could be classified as tolerant to changes in environmental conditions and particularly nutrients. Limnothrix sp. was observed to occur in farmland sites and rangeland sites rather than the forested site. These sites were highly disturbed with a lot of nutrients influx. Therefore, it can be deduced that this group of freshwater attached algae also preferred a nutrient rich environment with high light intensity hence good indicators of water quality.

Development of algal periphyton biomass may also be affected by other factors such as the changes in river discharge. Wooten et al. (1996) observed that frequent disturbances brought by storm events reduce the ability of algal periphyton to recolonize by scouring them off from the substrata. In areas with very low disturbance regimes such as groundwater-fed streams having hydrologically stable streams one would expect thick mats of algal periphyton. However such areas may also have high densities of grazers which may again constrain algal periphyton biomass accumulation. Thus, the greatest response of periphyton biomass to nutrients is most likely when nutrients are just optimum for growth. High nutrients loading may results in decline of some species and emergence of others. In Nyangores there was decrease in Closterium sp. but with the emergence of Limnothrix sp. at the farmland site with increased nutrients concentrations. For this reason it can be deduced that the filamentous Limnothrix sp. in nutrient rich sections of Nyangores tributary rather than the forested areas with minimal or low nutrient concentrations. Studies have also shown that diatoms with more complex morphologies such as Fragilaria ulna thrive in nutrients rich waters and also in r-selected habitats which are usually unpredictable and disturbed (Biggs, 2000). In addition Gomphonema sp. and Navicula sp. were frequent in the assemblages in Nyangores tributary, concurring with the observations of Jüttner et al. (1996) who reported that diatom communities might respond differently to changes in nutrient concentrations. These authors found that Navicula cryptcephala significantly increased in abundance in nutrient enriched sites. Gomphonema sp. were reported by Fukushima et al. (1994) in rivers Toriyama and Izumi in Japan which had high nutrients concentrations from sewage treatment plants and domestic waste effluents. In this study Gomphonema...
Plate 1: Some of the common algal periphyton observed at x400 magnification from Nyangores tributary from February to May 2012 (Closterium, Navicula, Nitzschia and Fragilaria spp). Scale: 22.2 mm represented 1 unit on the stage micrometer

sp. were relatively high in farmland site which also received nutrients rich discharge from Tenwek sewage treatment plant. Furthermore, in River Ter (Catalonia, NE Spain), Sabater and Sabater (1988) reported that *Gomphonema parvulum*, (Kutz.) developed in sites that received high agricultural wastes.

Generally, members of the bacillariophytes with the highest percentage in biomass are the most important primary producers in Nyangores followed by cyanophytes. Extreme pollution resistant genera of bacillariophytes such as *Gomphonema* sp. and *Navicula* sp. were dominant among the 9 genera identified. These genera were cosmopolitan in distribution in Nyangores. Stevenson and Glover (1993) pointed that such spp have fast growth rates and abilities to monopolize space, low light intensity and limited nutrient conditions found in forested areas similar to the upstream of Nyangores.

CONCLUSION AND RECOMMENDATIONS

Nutrients concentrations varied significantly both temporally and spatially along Nyangores tributary with increased discharge downstream that was influenced greatly by land use. This was easily noted during the months of April and May when discharge was at peak. Algal periphyton community structure and biomass varied significantly with the changing nutrients concentrations. Therefore, the composition of periphyton assemblages is a useful metric to assess potential effects of land use at the catchment of riverine ecosystem. However, other physico-chemical variables are also potentially important in controlling periphyton distribution.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to GLOWS-Water Scholars and Florida University who provided funding for the study. The laboratory analysis was conducted at Egerton University and the institution with the staffs too is highly appreciated.

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