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Trophic State Indices And Phytoplankton Quotients For The Kisumu Bay, Lake Victoria

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ABSTRACT

This study aimed at estimating the Phytoplankton Quotients; the key indicators of eutrophication, of Kisumu Bay, and to determine eutrophic levels of the bay. The study was conducted from April 2009 to April 2010. Nutrients and phytoplankton analyses were determined by spectrophotometric and microscopic techniques, respectively. Significantly higher ($p<0.05$) chlorophyll a concentrations were recorded during the dry season compared to the rainy season. At 57%, Cyanophyceae was the most abundant phytoplankton group, followed by Chlorophyceae (28%), Desmidaceae (11%), Bacillariophyceae (4%) and Euglenophyta (1%). Among the Cyanophyceae, the most dominant species were Microcystis sp., Chroococcus sp., Anabaena sp and Cylindrospermopsis sp. Different phytoplankton distribution patterns were observed between the offshore Maboko station and the inshore stations. The mean phytoplankton quotient for Kisumu Bay was estimated to be 4.1, indicating high eutrophic status. The elevated eutrophic state could be attributed to high nutrient loads from anthropogenic activities, industrial and municipal wastes, and stricter enforcement of the established policies on the quality of discharges is recommended. There is also a need for environmental education and public awareness targeting the lake basin inhabitants to abate pollution in the lake.

Keywords: Anthropogenic activities, Eutrophication, Nutrients, Nyanza gulf, Trophic.

1.INTRODUCTION

Many of the world's freshwater lakes suffer from nutrient loading (Hecky, 1993). Eutrophication is thought to be the primary cause of freshwater impairment (Selman and Greenhalgh, 2009). Like many freshwater bodies in the world, Lake Victoria has experienced deterioration in water quality and high levels of ecological stress in recent years, a situation that has largely been attributed to escalation of anthropogenic activities within the riparian areas. This has contributed to eutrophication and contamination of the lake waters, with grave implications on the fisheries economy of the region (Hecky, 1993; Kaufman, 1992; Hecky, *et al*., 1994). Scientific evidence of nutrient enrichment in Nyanza Gulf has been reported by (Lung'ayia *et al.* 2001; Gikuma-Njuru and Hecky 2005). Consequently, limnological work on Nyanza Gulf has been studied since 1960s, and has shown increased hypolimnetic anoxia, increased nitrogen and phosphorus inputs and persistent high water levels accompanied by decline of available silicon (Gophen *et al*., 1995). In addition, phytoplankton productivity and shifts from diatom to blue-green algae dominance has occurred. Consequently, enhanced chlorophyll *a* levels were reported in the late 1980s and early 1990s (Hecky, 1993). Nitrogen and phosphorus are particularly cited as critical to biological processes in aquatic ecosystems, results in increased biomass production, upsetting the natural balance of these ecosystems (Selman and Greenhalgh, 2009).

Nyanza Gulf is currently exhibiting characteristic symptoms of eutrophication, as evidenced by mats of floating macrophytes, high turbidity, oxygen depletion, and changing phytoplankton community structure. Despite all these changes, no trophic state indices have been calculated for Nyanza or Kisumu Bay. Effective management of water quality and lake pollution is only possible with improved scientific understanding of the limnological and hydrological aspects of the lake and anthropogenic effects on the lake environment (Hecky, 1993; Kaufman, 1992; Hecky, *et al.*, 1994). The aim of this paper was to address the trophic status of Nyanza gulf waters and offer a scientific understanding of the water quality and pollution level through trophic state indices and phytoplankton quotients for the gulf.

2. MATERIALS AND METHODS

Study area and Sampling

The study of Phytoplankton Quotients (P.Q.) and Trophic State Indices (TSI) was conducted between April 2009 and April 2010 in Kisumu Bay taking into consideration the dry season (August-September) and the wet season (March -May). Three sampling stations were set at the discharge points of rivers Kisian (S1) and Kisat (S3), and the Yacht club (S5) to capture the effects of stream inputs. Two other stations were located at the Kisumu railways pier (S4) and Maboko (S2), in the inner Winam Gulf, to capture the effects of runoff and the ensuing dilution, Figure 1. The sampling stations were positioned using a Magellan Global Positioning System (GPS) 315 meridian. Sampling was done on a monthly basis for a year. All samples were taken at a depth of 1 m. *In situ* parameters were measured before sampling. Secchi depth transparency was measured using a standard 20 cm diameter Secchi disk, water turbidity and pH were measured using a Hatch Turbidimeter 2100 P, while pH was measured using a digital Mini pH meter Model 49. Water depth, temperature, conductivity and chlorophyll a were measured using a submersible Conductivity-Temperature-Depth, CTD (Sea-bird Electronics®) profiling system. Water samples were collected using a 2.5 litre Van Dorn water sampler, and placed in sterile plastic sample bottles. Total alkalinity and total hardness were determined using the methods of (APHA ,1995) by titration of 50 ml of water sample with 0.02 N HCI to a pH of 4.5, using methyl orange indicator and 0.02 N EDTA respectively. Samples for nutrient analysis were stored in an ice box and transported to the laboratory for analysis within 24-48 hours. Phytoplankton samples were collected using a Van Dorn water sampler (quantitative analysis) and a 10 μm phytoplankton net (qualitative analysis), fixed using acidic Lugol's solution and stored in plastic vials for laboratory analysis. Total suspended solids and total dissolved solids were determined by filtering 50mls of water through a pre-weighed standard glass-fiber filter into a dry and pre-weighed evaporating dish. The residue retained on the filter paper was dried to a constant weight in an oven at 103 to 105°C for at least 1 hour, while the filtrate in the evaporating dish was evaporated in an oven, at 103 to 105°C for at least 1 hour. These were then cooled in a desiccator and weighed. The cycle of drying, cooling in a desiccator, and weighing was repeated until a constant weight was obtained. The increase in weight of the filter represented the total suspended solids (TSS) and was calculated by multiplying the difference in weight of filter + dried residue from weight of filter alone by 1000, then divided by sample volume (50ml). The increase in weight of the evaporating dish represented the total dissolved solids (TDS), calculated as by multiplying the difference in weight of evaporating dish + weight of dried residue from weight of evaporating dish alone by 1000, then divided by sample volume (50ml).

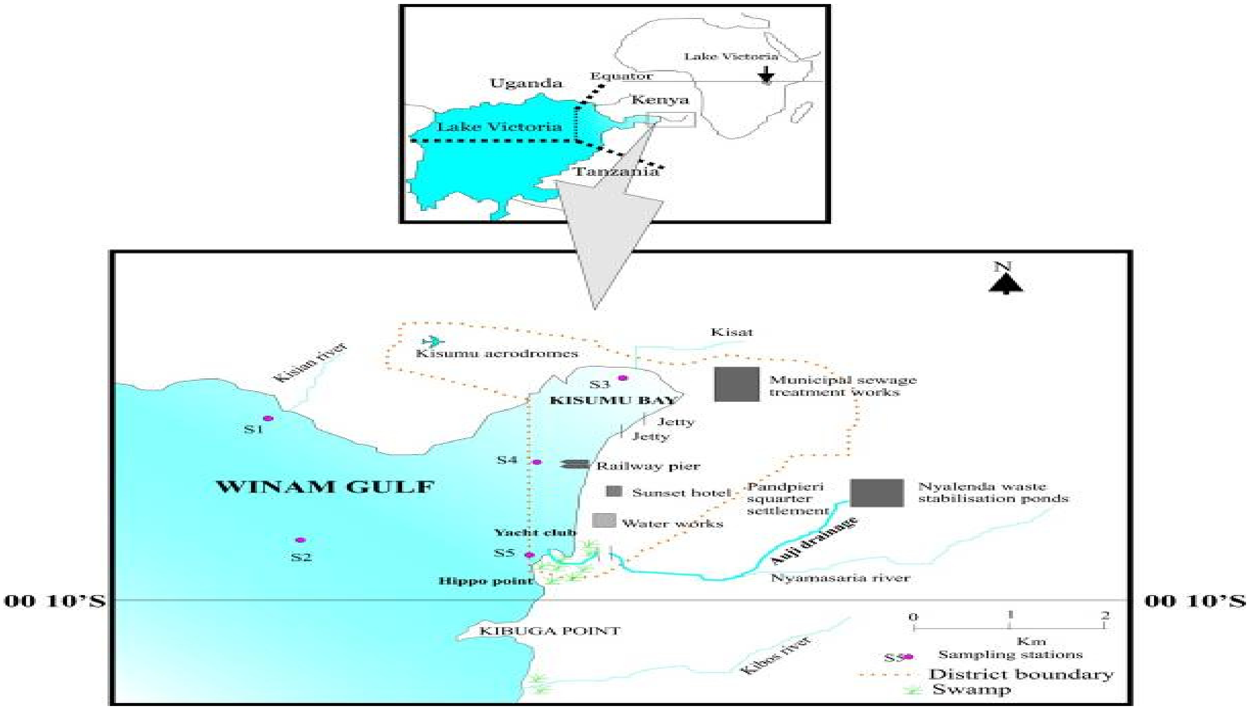

Figure 1: Map of Winam Gulf showing Kisumu Bay, its drainage system, and the sampling stations (S1- R. Kisian, S2 – Maboko, S3 - R. Kisat, S4 - Railway Pier and S5 - Kisumu Yacht Club).

Nutrient Analyses

Ammonia content was analyzed using phenol hypochlorite method while nitrates and nitrites were analyzed using the Cadmium – reduction method (USEPA, 1979). Total nitrogen and total phosphorous were determined on unfiltered water samples. Digestion of TN with potassium per sulfate and autoclaving process was carried out to convert organic nitrogen to nitrate nitrogen while TP was oxidized using hot 5% potassium per sulfate in distilled water, autoclaved then further cooled at room temperature to liberate organic phosphorus as inorganic phosphate. Soluble reactive phosphorous (PO_4 – P) was analyzed using the Ascorbic acid method. Silicates were analyzed using the heteropoli blue technique according to (APHA ,1995).

Phytoplankton analyses

Phytoplankton cells were identified, and counted using an inverted microscope at 400x magnification. Counts were made of all individual cells, colonies and filaments. Phytoplankton identification was done using the methods of (Huber–Pestalozzi , 1938;Cocquyt *et al.* 1993). Algal biomass determination was done by counting and measuring algal cells and the total cell count converted to cell biovolume using appropriate geometric formulae as outlined in (Wetzel and Likens ,2000).

RESULTS

Physico-Chemical Parameters

The physical and chemical characteristics of Kisumu bay for the period 2009/2010 are shown in Tables 1 and 2. Ambient water temperatures for Kisumu bay ranged between 26.3°C and 28.5°C, with significantly lower temperatures (ANOVA, $p<0.05$) experienced during the wet season. Dissolved oxygen levels varied significantly among sampling stations (ANOVA, $p<0.05$), with the lowest (4.6 ± 0.4 mg/l) levels recorded at the inlet of River Kisat and the highest (8.0 ± 0.2 mg/l) at the offshore Maboko station.

The concentrations of dissolved and suspended solids in the water also varied among sampling stations, with highest TDS (746.4 ± 48.1 mg/l) level recorded at the mouth of River Kisian, and the lowest (292.2 ± 26.9 mg/l) at Auji drainage/River Nyamasaria inlet. Similarly, highest (1597.7 ± 57.9 mg/l) and lowest (621.7 ± 7.4 mg/l) TSS levels were recorded at the inlets of rivers Kisat and Auji, respectively. An average pH of 7.7 ± 0.1 was recorded for the bay during this period. Kisumu Bay waters recorded low conductivity levels (Av. 178.7 ± 12.1 µS/cm) and even lower Secchi depth measurements (< 0.3 m) during the same period. There were variations in turbidity among sampling stations (Table 1) and between the wet and dry seasons (Table 3), with the highest (358.2 ± 7.2 NTU) and lowest (197.4 ± 17.3 NTU) turbidity levels recorded at the Railways pier and Auji drainage/River Nyamasaria inlet stations, respectively.

Kisumu bay recorded relatively high TP (289.6 ± 8.9µg/l) and TN (1518.5 ± 7.0µg/l) levels during the study period, table 2. Significant spatial variations (ANOVA, $p<0.05$) in total phosphorus (TP) and total nitrogen (TN) levels were observed within Kisumu Bay, with River Kisat and River Kisian inlet stations recording higher levels of both nutrients compared to other stations. The relative levels of total nitrogen and phosphorus and the TN/TP ratio in the bay, however, remained constant throughout the year. Silica levels in the bay also varied with location and season.

Spatial and seasonal variations in chlorophyll *a* levels were also observed in Kisumu Bay. While the highest concentrations of chlorophyll *a* (32.6 ± 5.7 µg/l) were recorded at the R. Kisat inlet, the offshore station (Maboko), recorded significantly lower mean chlorophyll *a* levels (18.4 ± 1.1µg/l) during the wet season, Table 3. Regression analyses revealed significant negative relationship between chlorophyll *a* levels and total suspended solids, water turbidity, total nitrogen and total phosphorus levels in the water ($p<0.01$), Figure 2. Secchi transparency measurements were also significantly negatively related to the chlorophyll *a* levels, while TDS showed a significant positive relationship with chlorophyll *a* levels in the lake waters.

Phytoplankton Species Composition, Distribution and Abundance.

At 57% the Cyanophyceae were the predominant phytoplankton family in Kisumu bay (Figure 3). Other major families in the bay included the Chlorophyceae (28%), Desmidaceae (11%), Bacillariophyceae (4%) and Euglenophyceae (1%). Among the Cyanophyceae, the most abundant species were *Microcystis* sp., *Anabaena* sp. *and Cylindrospermopsis* sp. (Table 4). Other species recorded in significant numbers included: *Nitchzia* sp., *Chroococcus* sp., *Tetraedron* sp., *Euglena* sp., *Cosmarium* sp., *Planktolyngbya* sp., *Stephanodiscus* sp., *Phacus* sp., *Aulacoseira* sp., *Coelastrum sp*., *Navicula* sp., *Aphanocapsa* sp. *and Kirchnella* sp. in a descending order.

A list of the major phytoplankton families and genera recorded in Kisumu bay during this study, and their relative abundance is given in Table 4 and Figure 3, respectively. In all, 50 genera of phytoplankton were identified in the 5 sampling stations. In terms of diversity, the Chlorophyceae were the most diverse with 18 species recorded, Cyanophyceae with 11 species, Bacillariophyceae with 8 species, Euglenophyceae with 6 species, Desmidaceae with 5 species and the Dinophyceae with only 2 species in the bay. There were no significant seasonal variations in the composition and relative abundance of phytoplankton taxa.

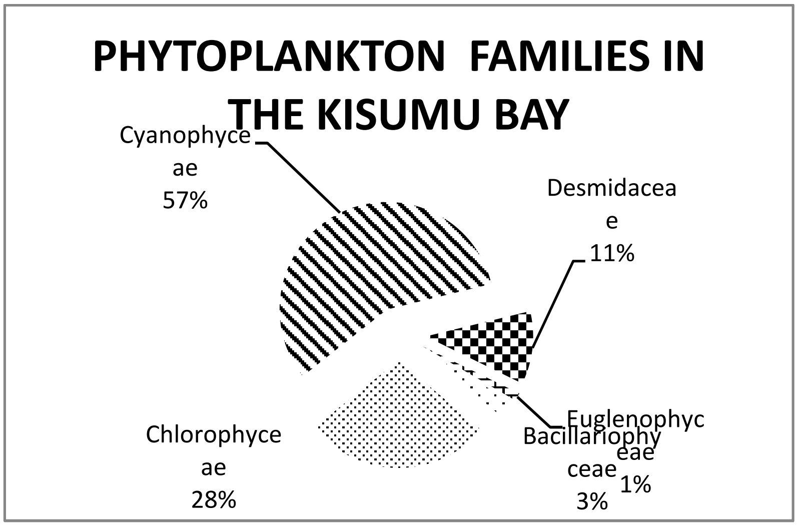

Figure 2: The composition and relative abundance of the major phytoplankton families found in Kisumu bay during the 2009/2010 period.

Phytoplankton Quotients and Trophic State Indices

The phytoplankton quotients varied significantly with location and season (Table 5). The highest PQ (6.4 ± 1.6) was recorded at the mouth of River Nyamasaria; while the lowest PQ (2.3 ± 1.5) was recorded at the mouth of River Kisat. The compound PQ for the bay was estimated to be 4.09. The Trophic State Indices (TSI) for Kisumu bay is given in (Table 6). While there were no spatial differences in TSI values for TP and TN, the TSIs for chlorophyll *a* differed markedly between stations, with the highest TSI (51.8 ± 0.4) being recorded at Kisat station while the lowest TSI (37.2 ± 0.3) was recorded at the offshore Maboko station. The combined TSI for the bay was estimated to be 145.263 ± 4.1, a value that was much higher than the universally acceptable values for quality waters (< 70).

DISCUSSION

Physico-chemical Parameters

Results showed that ambient water temperatures for Kisumu Bay ranged between 26.3^{o}C and 28.5^{o}C; with significantly lower temperatures during the wet season. The temperature measurements recorded in Kisumu Bay reflected the general diurnal temperatures reported for L. Victoria waters (LVEMP, 2000). The results also indicated that dissolved oxygen levels in the bay varied significantly among sampling stations, but were within the internationally acceptable levels (APHA, 1995; OECD, 1982) (Table 3). Low DO levels recorded at Kisat Station, coincided with high levels of TSS reflecting the effect of point source discharges from the river Kisat, consistent with the often-reported inverse correlation between DO and TSS levels (USEPA, 2000; Gichuki *et al*, 2006) that is usually associated with high nutrient inputs. Even though DO levels as low as 1 mg/l have been recorded in the wider L. Victoria waters (Verschuren *et al*., 2002; Odada *et al*., 2004), the levels reported here indicate that Kisumu Bay has enough dissolved oxygen to sustain a healthy ecological diversity. The highest levels of TDS (746.4 ± 48.1 mg/l) were recorded at the mouth of R. Kisian, a river surrounded by a continuously weathering rocky catchment, which contributes to the relatively high suspended solids load into the bay, while the lowest (292.2 ± 26.9 mg/l) was recorded at the Auji drainage/R. Nyamasaria inlet that flows gently into Kisumu Bay, allowing for sedimentation of solids before reaching the mouth of the inlet. The Secchi depth measurements recorded during this study were even lower (< 0.3m), than those reported successively by (Lehman and Brandstrator ,1994 ; Sitoki *et al*., 2010), indicating a state of continual degradation of the bay. The Kisumu

Bay waters, however, recorded low conductivity levels (Av. 178.7 µS/cm) similar to those reported by (Sitoki *et al*., 2010). The low conductivity levels were probably expected considering the low TDS levels recorded in the bay during this study. High turbidity levels (> 197 NTU's) were recorded in the bay indicating that the waters of the bay were murky and of poor quality. The variability of environmental parameters among sampling stations indicate presence of significant environmental impacts exerted on the quality of the bay's waters by the inflows from the riparian areas around Kisumu Bay, and that seasonality has a significant influence on these impacts.

Nutrients levels and chlorophyll a concentrations of Kisumu Bay

The concentration of phosphorus in most freshwaters range between 2 and 20 µg/l, whereas that of nitrogen seldom exceeds 100µg/l. The nutrient (TN and TP) levels(Table 3) recorded in Kisumu Bay during this study were not only much higher than the normal freshwater levels, but also higher than those previously recorded within the Nyanza gulf by (Hecky ,1993; Hecky *et al*. 1996; Lung'ayia *et al*., ,2000; Gikuma-Njuru and Hecky ,2005 ;Gichuki *et al*. 2006). These high TP and TN levels may be a reflection of high nutrient inputs resulting from anthropogenic activities around the bay area and from Kisumu City. Indeed, the elevated TP and TN levels, which were more pronounced at the Kisat and Kisian sampling stations, and at the Auji-Nyamasaria inlet, especially during the rainy season, may be a confirmation of the influence of Kisumu City and the riparian areas on Kisumu Bay that is being exerted through the Kisat-Auji-Nyamasaria drainage systems. Spatial and seasonal variations in the levels of chlorophyll *a* were also observed in Kisumu Bay. Variations in levels of chlorophyll *a* coincided with spatial distribution of nutrients, and seasonal variation in the volume of discharge due to runoff. For example, while the highest concentrations of chlorophyll *a* were measured at R. Kisat inlet, that is associated with sewage discharge, and high nutrients levels, which lead to high algal production rates, the offshore Maboko station recorded significantly lower mean chlorophyll *a* levels during the wet season, probably as a result of a combination of dilution effects and increased turbidity due to sediment inputs from river Kisian, a fact that is amply supported by the significant negative correlation observed between chlorophyll *a* levels in the water and total suspended solids, water turbidity and Secchi transparency measurements in this study.

Phytoplankton population structure, PQ and TSI

Determination of the trophic state of a water body is based upon the levels of phosphorus and nitrogen, and the phytoplankton biomass in the water, with high nutrient concentrations being associated with eutrophication and algal blooms, whereas high silica content leads to high diatom populations. The nitrogen phosphorus ratio (N:P ratio), on the other hand, determines the phytoplankton community structure, which in turn forms the basis for the determination of the phytoplankton quotient of a water body. The low TN:TP ratio (< 10) for Kisumu Bay indicates that the bay is nitrogen limited (Carlson, 1977), and increase in nitrogen concentration results in increased phytoplankton production, a fact that is supported by the higher chlorophyll *a* levels recorded at the Kisat and Auji-Nyamasaria inlets, and during the high runoff wet season. The high phosphorus loading and nitrogen limitation favoured the proliferation of the Cyanobacteria, which currently dominate the algal population in the bay. The Cyanobacteria pose a threat to aquatic life since they produce algal toxins that are harmful to aquatic organisms (Kilham, 1990; Hecky, 1993 and Gichuki *et al*, 2006). The low SiO_2 levels in the bay were mirrored in the low Bacillariophyceae populations recorded. This research confirms the increasing level of the Myxophyceae/Cyanophyceae families and decreasing levels of the Chlorophytes in Nyanza gulf that was previously reported by (Muggide ,1993 Lung'ayia *et al*., 2000).

Prevailing Trophic State of Kisumu Bay

In standing waters, water quality may be determined by an array of physical and biological factors. Quality determination for Kisumu Bay waters was based upon the levels of TP, chlorophyll *a* concentration, TSS and TDS levels as well as the TSI and PQ prevailing in the waters at the time of the study (Table 3, 5, and 6). Kisumu bay had a compound PQ ranging between 2.3 and 6.4, placing it within the eutrophic class of the (Nyaggard ,1949) classification, which also classifies a eutrophic water body as that having Chlorophycea, Myxophycea and Bacillariophyceae quotients ranging between 0.7 - 3.5, 0.8 - 3.0 and 0.2 – 3, respectively, ranges that were surpassed in Kisumu Bay. This may imply that the bay is in worse state of eutrophication than previously thought (Gichuki, 2000; Gichuki *et al*., 2006). The higher than normal Carlson's TSI values placing the bay within the hypereutrophic category attests to this observation. Results from this study indicate that TN ($r^2 = 0.8888$, $p < 0.01$) and Turbidity ($r^2 = 0.8451$, $p < 0.01$) were the best indicators of the trophic state of Kisumu bay.

Other good indicators included TP ($r^2 = 0.8309$) and Secchi depth ($r^2 = 0.733$).

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TABLES

TABLE 1: Mean (± S.E.) values for physico-chemical parameters and chlorophyll a for Kisumu bay during the study period, April 2009 – March 2010. Significant spatial differences ($p < 0.05$) are depicted by different superscripts.

Parameter	Kisian	Maboko	Kisat	Railways pier	Nyamasaria
Temperature (° C)	28.5 ± 0.4^b	26.3 ± 0.5^a	28.5 ± 0.5^b	27.5 ± 0.4^b	27.0 ± 0.4^b
Conductivity (µS/cm)	184.3 ± 2.4	165.4 ± 4.5	195.2 ± 2.6	184.6 ± 2.8	163.8 ± 8.1
Secchi depth (m)	0.2 ± 0.01	0.3 ± 0.03	0.1 ± 0.01	0.2 ± 0.01	0.2 ± 0.01
DO (mg/l)	5.6 ± 0.4^b	8.0 ± 0.2^c	4.6 ± 0.4^a	5.6 ± 0.4^b	5.7 ± 0.3^b
pH	7.8 ± 0.1	7.87 ± 0.08	7.9 ± 0.07	7.5 ± 0.08	7.7 ± 0.06
TDS (mg/l)	746.4 ± 48.1^c	392.2 ± 36.5^b	687.1 ± 38.6^c	620.2 ± 14.6^c	292.2 ± 26.9^a
TSS (mg/l)	1597.7 ± 57.9^c	795.0 ± 26.8a	1147.3 ± 28.8^b	1171.7 ± 16.3^b	621.7 ± 7.4^a
Turbidity (NTU)	296.7 ± 13.3^b	243.5 ± 10.6^b	261.6 ± 11.5^b	358.2 ± 7.2^c	197.4 ± 17.3^a
Chlorophyll *a* (mg/l)	30.5 ± 3.5^b	13.2 ± 1.9^a	32.6 ± 5.7^b	30.3 ± 3.3^b	31.9 ± 3^b

TABLE.2: Mean (± S.E.) values for nutrients concentrations for Kisumu bay during the study period, April 2009 – March 2010. Significant spatial differences ($p < 0.05$) are depicted by different superscripts.

Parameter	**R. Kisian**	**Maboko**	**R. Kisat**	**Railways pier**	**R. Nyamasaria**
NO_3 (μg/l)	40.6 ± 2,8^{a}	42.1 ± 3^{a}	46.3 ± 3.3^{b}	42.0 ± 2^{a}	46.3 ± 2.9^{b}
NO_2 (μg/l)	20.9 ± 2.1^{a}	28.6 ± 2.6^{b}	25.3 ± 2.9^{b}	21.3 ± 1.6^{a}	21.5 ± 1.76^{a}
NH_4 (μg/l)	91.4 ± 5.8^{a}	104.6 ± 8.7^{b}	136.1 ± 8^{c}	111.3 ± 31^{b}	117.6 ± 12.1^{b}
TN (μg/l)	1572.1 ± 2.2^{b}	1483.2 ± 15^{a}	1527.8 ± 12.2^{b}	1480.3 ± 19.9^{a}	1466.8 ± 2.4^{a}
SRP (μg/l)	141.9 ± 10.3	139.3 ± 6.9	138.1 ± 12.7	141.2 ± 9.1	132.9 ± 8.13
TP (μg/l)	307.6 ± 4.6^{b}	280.6 ± 4.3^{a}	315.2 ± 3.7^{b}	276.1 ± 2.3^{a}	256.7 ± 3.7^{a}
SiO_2	12.2 ± 1.7^{a}	25.0 ± 1.3^{b}	28.4 ± 2.5^{b}	26 ± 2.5^{b}	23.7 ± 1.9^{b}
TN:TP ratio	5.1 ± 0.07	5.3 ± 0.11	4.8 ± 0.06	5.4 ± 0.04	5.7 ± 0.07

TABLE 3: Seasonal variations in physico-chemical and nutrients characteristics of Kisumu bay during the 2009 – 2010 period. Significant seasonal differences ($p < 0.05$) are depicted by different superscripts.

PARAMETER	**DRY SEASON**	**WET SEASON**
Temperature ^{0}C	28.1 ± 0.2^{b}	26.7 ± 0.1^{a}
Conductivity (μs/cm)	165.0 ± 3.6	166.7 ± 3.7
D.O.(mg/l)	5.9 ± 0.2	6.3 ± 0.2
Secchi depth(m)	0.22 ± 0.01	0.22 ± 0.01
TDS(mg/l)	287.7 ± 2.0	286.99 ± 2.0
TSS(mg/l)	1427.2 ± 5.0	1327.0 ± 4.0
Turbidity (NTU)	227.4 ± 8.8^{a}	268.6 ± 8.9^{b}
Ph	7.7 ± 0.1	7.8 ± 0.0
Chlorophyll *a*	28.8 ± 2.4^{b}	18.4 ± 1.1^{a}
SiO_2	23.9 ± 1.3^{a}	28.1 ± 1.2^{b}
SRP	140.2 ± 4.8	139.4 ± 5.8
NH_4	107.6 ± 5.4	109.7 ± 6.3
$N0_3$	41.7 ± 1.6	44.5 ± 1.6
$N0_2$	20.8 ± 0.9^{a}	25.5 ± 1.5^{b}
TN	1501.2 ± 8	1518.5 ± 7.0
TP	280.8 ± 4.1	289.6 ± 3.8
TN:TP	5.4 ± 0.1	5.3 ± 0.1

TABLE 4: List of the major phytoplankton families and genera recorded in Kisumu bay during the 2009/2010 study.

FAMILY	GENUS
BACILLARIOPHYCEAE	*Amphora*
	Aulacoseira
	Cyclotella
	Cymbella
	Diatoma
	Navicula
	Nitchzia
	Stephanodiscus
CHLOROPHYCEAE	*Tetraedron*
	Ankistrodesmus
	Botryococccus
	Chodatella
	Coelastrum
	Dictyosphaerium
	Gonatodesmidson
	Kirchnella
	Monoraphidium
	Oocystis
	Pediastrum
	Scenedesmus
	Schroidera
	Schroederiella
	Ceolastrum
	Coenocystis
	Rhapidium
	Surillella
DESMIDACEAE	*Closterium*
	Crucigenia
	Cosmarium
	Straurastrum
	Cosmarium
DINOPHYCEAE	*Synedra*
	Glenodinium
EUGLENOPHYCEAE	*Euglena*
	Phacus
	Stromonas
	Trachelemonous
	Spurrillina
	Fragillaria
CYANOPHYCEAE	*Coelomoron*

FAMILY	GENUS
	Anabaena
	Aphanocapsa
	Chroococcus
	Cylindrospermopsis
	Microcycstis
	Planktolyngbya
	Pseudoanabaena
	Romeria
	Anabaenopsis
	Merismopedia
	Aphanothece

TABLE 5: Estimates of the phytoplankton quotients for the different sampling stations and the compound quotient for Kisumu bay for the period 2009 - 2010. Stations marked with different superscripts were significantly different ($p < 0.05$) for the respective quotients.

Station	Bacillar Q	Chloro Q	Eugl Q	Myxo Q	CQ
Kisat	2.2 ± 0.5 ^{a}	3.1 ± 1.0 ^{b}	2.4 ± 0.9 ^{c}	0.3 ± 0.2 ^{a}	2.3 ± 1.5 ^{a}
Kisian	2.2 ± 1.1 ^{a}	1.4 ± 0.5 ^{a}	0.2 ± 0.1 ^{a}	2.7 ± 1.7 ^{c}	2.9 ± 1.3 ^{a}
Maboko	0.7 ± 0.3 ^{b}	2.0 ± 1.5 ^{ab}	0.2 ± 0.4 ^{a}	3.3 ± 1.3 ^{c}	2.7 ± 1.6 ^{a}
Railway pier	2.2 ± 1.0 ^{a}	1.5 ± 0.8 ^{a}	1.1 ± 0.5 ^{b}	4.6 ± 1.8 ^{C}	4.9 ± 1.9 ^{b}
Nyamasaria	2.5 ± 1.3 ^{a}	0.7 ± 0.3 ^{c}	1.9 ± 0.9 ^{c}	1.7 ± 0.7 ^{b}	6.4 ± 1.6 ^{c}
Average	**2.0 ± 0.3**	**2.1 ± 0.5**	**1.1 ± 0.4**	**2.9 ± 0.7**	**4.1 ± 0.7**

TABLE 6: Estimates of the Trophic State Indices for Kisumu bay for the period 2009 - 2010. Stations marked with different superscripts were significantly different ($p < 0.05$) for the respective indices.

Stations	**TSI (Chlor *a*)**	**TSI (TP)**	**TSI (TN)**
Kisat	$51.8 \pm .3^{c}$	180.3 ± 9.0	180.3 ± 9.9
Kisian	$42.0 \pm .5^{ab}$	185.7 ± 5.6	185.9 ± 5.6
Maboko	37.2 ±.3a	195.5 ±7.1	195.5 ±7.1
Railways pier	$43.5 \pm .4^{b}$	189.6 ± 3.6	189.6 ± 3.6
Nyamasaria	$45.1 \pm .4^{bc}$	187.2 ± 4.4^{A}	187.2 ± 4.4
Stations	TSI2 (TP)	TSI2 (TN)	TSI AVER.
Kisat	272.3 ± 3.2	216.2 ± 4.0	139.3 ± 5.4
Kisian	270.3 ± 9.1	206. 6± 6.3	144.3 ± 13.8
Maboko	270.6 ± 3.6	210.9 ± 4.3	132.6 ± 17.8
Railways pier	265.4 ± 4.9	216.0 ± 6.6	143.5 ± 12.9
Nyamasaria	266.5 ± 5.2	208.0 ± 5.0	150.0 ± 13.8

TABLE 7: A comparison of the physico-chemical parameters measured in Kisumu bay during the 2009 – 2010 period and the internationally (WHO) accepted levels.

Parameter	**Levels in Kisumu bay**		**WHO Standards**
	Dry Season	Wet Season	
Temperature	28.1 ± 0.2[b]	26.7 ± 0.1[a]	-
Conductivity	165.0 ± 3.6	166.7 ± 3.7	10 – 1000 µS/cm
DO	5.9 ± 0.2	6.3 ± 0.2	8 – 15 mg/l @ 25°C
Secchi depth	0.22 ± 0.01	0.22 ± 0.01	-
TDS	287.7 ± 2.0	286.99 ± 2.0	< 1200 mg/l
TSS	1427.2 ± 5.0	1327.0 ± 4.0	25 – 80 mg/l
Turbidity	227.4 ± 8.8[a]	268.6 ± 8.9[b]	< 1000 NTUs
pH	7.7 ± 0.1	7.8 ± 0.0	6.5 – 9.0
Chlorophyll *a*	28.8 ± 2.4[b]	18.4 ± 1.1[a]	-
SiO_2	23.9 ± 1.3[a]	28.1 ± 1.2[b]	-
SRP	140.2 ± 4.8	139.4 ± 5.8	-
NH_4	107.6 ± 5.4	109.7 ± 6.3	< 3 mg/l
NO_3	41.7 ± 1.6	44.5 ± 1.6	< 5 mg/l
NO_2	20.8 ± 0.9[a]	25.5 ± 1.5[b]	< 1 mg/l
TN	1501.2 ± 8	1518.5 ± 7.0	< 6 mg/l
TP	280.8 ± 4.1	289.6 ± 3.8	< 1 mg/l

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