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Research Paper

Assessment of water quality and primary productivity characteristics of Volta Lake in Ghana

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ABSTRACT

Physico-chemical and primary productivity studies were undertaken at the northern reverine segment of the Volta Lake, Yeji, at two southernmost lacustrine areas (Kpando-Tokor and Dzemeni) and one below the dam (Kpong Headpond). The studies were conducted from June 2006 to April 2008 at different depths (0, 2, 4, 6 and 8 m). The mean surface dissolved oxygen levels at the 4 stations were comparable and varied between 7.3 and 8.1 mgL^{-1}. Dissolved oxygen decreased with increasing depth but with considerable amount of oxygen detected even at 12 m depth, indicating a well oxygenated Lake. Mean pH values ranged from 6.8 to 7.7. Transparency values ranged from 20 to 320 cm with Yeji recording relatively low values. Compared with earlier studies, transparency had reduced over the years at Yeji due to increase in suspended particles as a result of human activities. Concentrations of chemical constituents at 100 m from the shores of the Lake were similar to that of 500 m, suggesting a well mixed Lake. Generally, the nutrient levels in the Volta Lake were low indicating that the Lake is not eutrophic. The average values of temperature, pH and dissolved oxygen are considered suitable for normal aquatic life. A total of 73 algal taxa were encountered during the study. These include 37 Green algae (Chlorophyta), 50.68%; 16 Blue-Green algae (Cyanophyta) 21.92% and 20 Diatoms (Bacillariophyta) 27.40%. Yeji was richer in Green algae (27 taxa) compared to Dzemeni and Kpando-Tokor (24 and 23 each) which were similar in green algae diversity. The Blue-Green algae and the Diatoms were about evenly occurring at the three stations on the Lake. Kpong Headpond was richer in Green and Blue-Green algae compared to stations on the main lake.

Key words: Physico-chemical, water quality, primary productivity, algae, diatoms, Lake Volta.

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INTRODUCTION

Reservoirs provide water for power generation, agriculture, industrial and domestic purposes. Most reservoirs play an important role in fish production in the tropics and contribute significantly to the national food and nutritional security levels and livelihoods of communities along their shores. For example, the number of fishing villages on shores of Volta Lake was 1,232 in 2003 and fishing is the basis for the livelihood of some 71, 861 fisher folks (MOFA, 2003). Although the Volta Lake was created primarily for the generation of hydroelectric power, its fisheries potential was anticipated and has indeed contributed towards food and nutritional security status of Ghana, by providing 90% of national freshwater fish production (Abban, 1999).

Since the formation of the Volta Lake in 1964, there has been a sizeable increase of human population in the Lake's watershed with corresponding increase in anthropogenic activities (Ntow, 2003). For instance, the Lake now serves purposes which include water supply, transportation, fishing and recreation. These activities may have led to changes in the quality of the Lake's water. Apart from limited studies undertaken during the formation years of the Lake (Biswas, 1966, 1969; Lawson et al., 1969; Entz, 1969), there has not been any regular monitoring of the physico-chemical parameters of the Lake. More recent work done by Antwi and Ofori-Danson (1993), Ofori-Danson and Ntow (2003) and Ntow (2003) on water quality are patchy and confined to Yeji and Kpong areas. This makes it difficult to establish trends in water quality since the inception of the Lake.

In anticipation of the fisheries potential of the Lake, studies of lake characteristics that influence fish production, such as phytoplankton availability, distribution and production as well as bio-chemical parameters that could influence the phytoplankton were assessed at the formative years of the Lake. In one of these studies, Lawson (1963), predicted changes in phytoplankton status in the lake which he said would be better understood in relation to the physico-chemical factor changes of the Lake water. Another phytoplankton study between 1964 and 1967, indicated that phytoplankton counts in the lake were higher during dry periods compared to wet or rainy seasons (Lawson et al., 1969; Biswas, 1966). The situation was attributed to a combination of low temperature, low light intensity and dilution of nutrients due to rains and mixing of surface and bottom waters during the rainy seasons. Biswas (1966) also indicated that high ammonia with low nitrate contributed to low phytoplankton production while high amounts of phosphate and nitrate boosted phytoplankton production. Increased phytoplankton activity increased dissolved oxygen status. Studies of distribution of phytoplankton in the lake at its formative years (1963-1966) also indicated that higher abundance of phytoplankton occurred in the southern sector, for example, Ajena (Stratum I) compared to the more northern segments, for example, Stratum III (Viner, 1966). The same study by Viner indicated that Diatoms (Bacillariophyta) to be more dominant in the south, Blue-green algae (Cyanophyta) to be more dominant in the north with the green algae (Chlorophyta) becoming abundant in the north of Kpando (Stratum III) with aging of the lake. Generally, however, according to Rajagopal (1969), phytoplankton in southern part of the lake was quantitatively and in diversity poorer than in the northern parts. For general primary productivity, Viner (1969) indicated productivity to be higher in shallow parts of the lake compared to deeper parts.

Photosynthetic primary production by phytoplankton in aquatic ecosystems gives an indication of the utilization of the Photosynthetically Active Radiation (PAR), (Talling and Lemoalle, 1998). This study comprises an estimate of the primary production of the Volta Lake in relation to selected environmental parameters such as oxygen concentrations, water temperature, secchi disc depth and conductivity.

This study was aimed at assessing and updating status of the Lake's water quality, primary productivity and its potential effects on fish production. Also, primary productivity in relation to chlorophyll-a content of the Lake is being investigated.

MATERIALS AND METHODS

The study area

Lake Volta lies between longitude 1° 30'W and 0° 20'E and Latitude 6° 15'N and 9° 10'N (Figure 1). At the maximum level, the lake has a volume of 149 km^3, a surface area of about 8500 km^2 and its length is 400 km. The mean depth is 19 m. It constitutes 3.6% of the surface area of Ghana. The Volta Lake (Figure 1) at its formative years was divided into eight segments called strata to facilitate hydrobiological and limnological studies.

The catchment area of the Volta basin is approximately 394,000 km^2 and shared by six countries- Mali, Benin, Togo, Burkina Faso, Ivory Coast and Ghana. The Volta basin system occupies about 70% of the total land area of Ghana, with the portion in Ghana representing about 42% of the total basin area. The main rivers draining the Volta basin system are the Black Volta, White Volta, Daka, Oti, Afram, Pru, Dayi and Asukawkaw.

The Volta basin is underlain by the Voltaian formation, comprised of sandstone, shales and mudstones. Another formation is pre-Cambrian, classified into Birimian, Buem and Tarkwaian rocks (Dickson and Benneh, 2004).

The climate of the basin is tropical continental or savanna type, with a single rainy season extending from May to October, followed by a prolonged dry season. The annual rainfall ranges between 1000 and 1150 mm.

Agriculture is the major land use in the basin, with most of the basin inhabitants being farmers engaged in both cultivation of crops and livestock rearing. The cropped areas are intensively cultivated, primarily with hoes. The remaining areas are characterised by extensive livestock grazing.

Water sampling at the locations indicated in Table 1 were undertaken from June 2006 at two monthly intervals till April, 2007 and quarterly from July 2007 till April 2008.

Physico-chemical sampling

Water samples were collected bi-monthly with a 1.5 L TPN Water sampler (Hydro-Bios Kiel) from various depths into clean 1 L plastic bottles.

Four sampling stations were chosen for the study for being areas of high fishing activity as well as landing sites. These were: Kpong, Dzemeni, Kpando-Tokor and Yeji

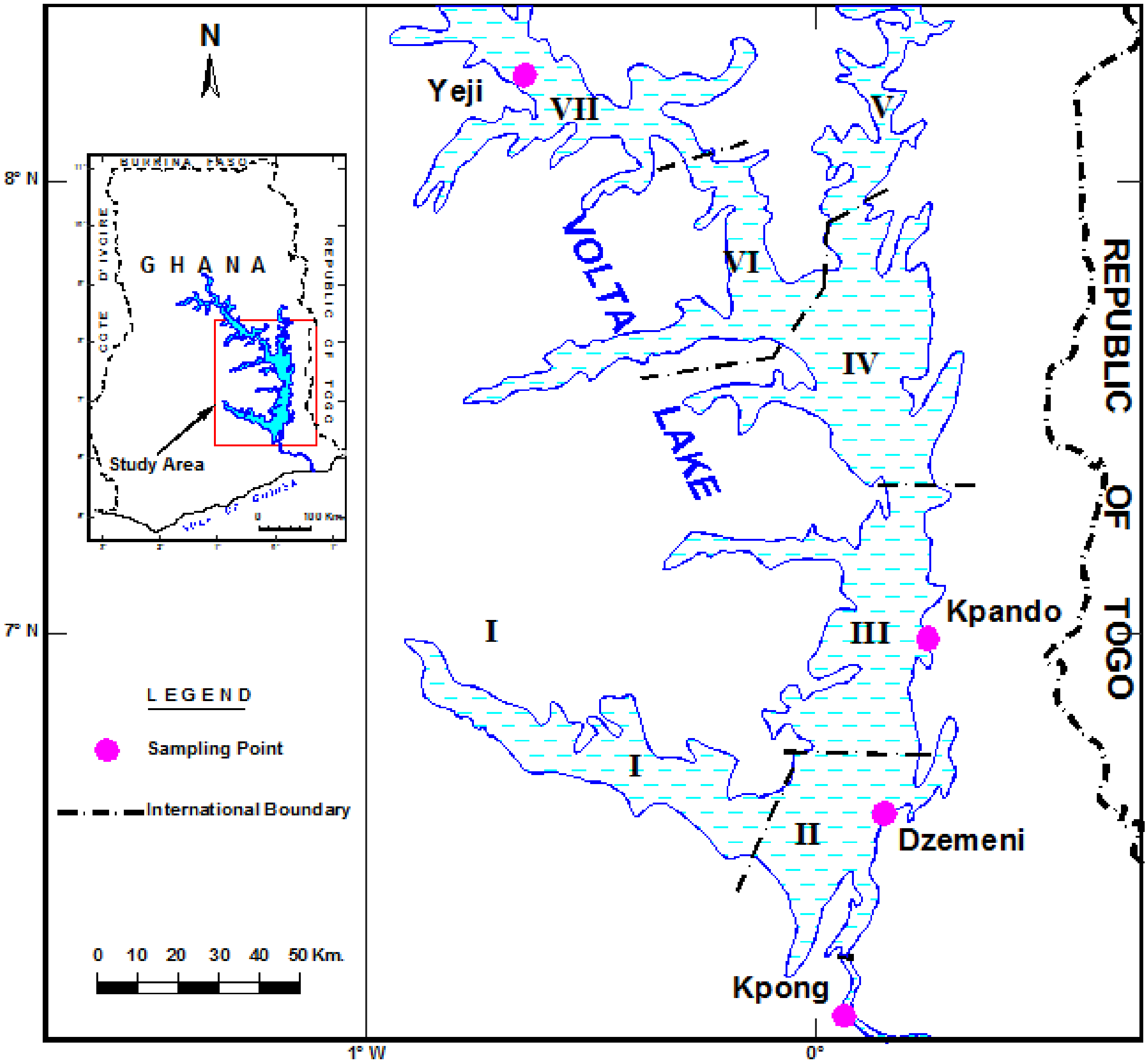


Figure 1. Map of the study area showing the sampling sites and Volta Lake segmentation: I = Afram arm, II = Lower main body, III = Middle main body, IV = Upper main body, V = Oti river arm, VI = Lower Volta riverine body, VII = Middle Volta riverine body, VIII = Upper Volta riverine body.

Table 1. Sampling sites and their relative locations.

Sampling site	GPS Coordinates	Relative Locations and main features
Kpong Headpond; (Below dam)	1. (N 06° 09.322′, E 000 ° 03.843′) 2. (N 06° 09.288′, E 000 ° 03.958′)	A headpond below the main dam formed from a smaller dam at Akuse
Dzemeni; (Stratum II)	1. (N 06° 36.140′, E 000 ° 09.441′) 2. (N 06° 36.150′, E 000 ° 09.171′)	Southern part of main Lake, very lacustrine.
Kpando-Tokor; (Stratum III)	1. (N 06° 59.497′, E 000 ° 15.120′) 2. (N 06° 59.227′, E 000 ° 15.076′)	South, next to stratum II lacustrine
Yeji (Stratum VII)	1. (N 08° 14.102′, W 000 ° 38.917′) 2. (N 08° 14.261′, W 000 ° 38.718′)	North, Riverine part of lake

Table 2. Mean ± SD Physico-chemical Characteristics of Volta Lake.

Station	Distance (m)	Temp. (ºC)	pH	Turb. (NTU)	NO_2-N (mgL^{-1})	NO_3-N (mgL^{-1})	NH_4-N (mgL^{-1})	PO_4-P (mgL^{-1})	DO (mgL^{-1})
	From shore	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Kpong	100	28.5±2.0	6.76±0.43	2.51±0.82	0.007±0.009	0.47±0.39	0.28±0.24	0.23±0.29	7.3±1.31
	500	27.9±2.05	6.90±0.34	2.14±0.35	0.009±0.010	1.97±0.69	0.26±0.17	0.26±0.25	7.3±0.96
Dzemeni	100	30.1±2.05	7.40±0.54	3.59±0.89	0.007±0.008	0.29±0.28	0.28±0.24	0.29±0.22	8.1±1.00
	500	30.0±1.58	7.45±0.67	3.08±0.70	0.007±0.006	0.36±0.37	0.29±0.22	0.23±0.21	7.9±1.10
Kpando	100	28.5±2.21	7.27±0.69	7.38±4.11	0.010±0.010	0.71±0.61	0.44±0.47	0.22±0.22	7.7±0.99
	500	28.5±2.17	7.44±0.64	4.64±1.58	0.007±0.009	0.37±0.40	0.29±0.24	0.19±0.20	8.0±1.43
Yeji	100	29.7±1.89	7.49±0.61	77.1±83.0	0.029±0.036	1.70±1.70	0.99±0.65	0.29±0.14	7.5±0.97
	500	29.8±1.70	7.66±0.64	80.8±92.0	0.021±0.022	1.19±1.17	1.30±0.51	0.30±0.25	7.3±0.90

located in Strata II, III and VII and in the head waters below the Akosombo dam. The sites were also chosen because of their accessibility by road and their peculiar locations in the various strata.

Samples were collected from about 100 m from the shore of the lake where influence of local run off from agriculture or settlements is expected to be significant and from about 500 m from the shore. Temperature, pH and transparency were measured in the field with temperature probe, HACH EC 20 potable pH meter and Secchi disc, respectively. Samples for Dissolved Oxygen (DO) determination were collected into 300 ml plain glass bottles and the DO fixed using azide modification of Winkler's method. The samples were kept in a cold box and transported to CSIR-Water Research Institute's Laboratory in Accra.

Phytoplankton studies

Phytoplankton samples were collected at about 100 m from the shore of the Lake and from about 500 m from the shore into 250 ml clean plastic bottles and preserved with 4% formalin. All samples were kept in a cold box and transported to the laboratory in Accra for analytical study. In the laboratory, water samples were well shaken and aliquots of 25 ml were transferred into counting chambers for microscopic study. Identification and enumeration of algae taxa was done using a Carl Zeiss inverted microscope as described by Lund et al. (1958). Sedimentation was carried out in counting chambers with a settling time of 4 h for every 1 cm of water column of the sample (Wetzel and Likens, 1990). All colonies and filaments were counted as individuals, and the average number of cells determined for 20 individuals and cell concentration calculated. In order not to contaminate the samples, counting chambers were cleaned with detergent after each sample analysis and the cover slides were also changed. Identification was carried out using the manual of algal species from Laboratoire D'Ichtyologie Museum National D'Histoire Naturelle, Paris.

Determination of Chlorophyll-a content in water samples

At each sampling station, water samples for Chlorophyll 'a' were collected into 1 L clean plastic containers and kept in the dark (usually in ice boxes because the green chlorophyll pigment degrades quickly in sunlight).

A volume of 1000 ml of water was filtered through Whatman GF/C filter paper. Ninety percent acetone was used to extract Chlorophyll-a into solution and centrifuged at 3200 rpm for 10 min and the supernatant poured off and measured at 663, 645 and 630 nm respectively using the spectrophotometer.

In the laboratory, the samples were kept in a refrigerator at 4°C until the analyses were completed. Method of analysis were the same as those described in the 'Standard Methods for the Examination of water and Wastewater (APHA, AWWA, WEF, 1998).

Electrical conductivity was measured with a Cyberscan 510 meter and turbidity was measured with a HACH 2100 P Turbidimeter. Diazotization for NO_2-N; hydrazine reduction for NO_3-N; direct nesslerization for ammonia nitrogen; stannous chloride for phosphate; and the Azide modification of Winkler for dissolved oxygen.

RESULTS AND DISCUSSION

Tables 2 to 4 present summary of the results on the water quality of the Lake Volta at Kpong, Dzemeni, Kpando-Tokor and Yeji. The results are further described in Figures 2 to 5.

Table 3a. List of algae recorded at all the sampling sites.

Green Algae (Chlorophyta)	Kpong	Dzemeni	Kpando-Tokor	Yeji
Actinastrum sp.	X	-	-	X
Ankistrodesmus falcata	X	X	X	X
Chlamydomonas sp.	X	X	X	X
Chlorella vulgaris	X	X	X	X
Chlorococcum sp.	X	-	-	-
Chlorogonium sp.	X	-	-	-
Closterium lanula	X	X	X	X
Coelastrum cambricum	X	X	X	X
Cosmarium panamense	X	X	X	X
Crucigenia sp.	-	-	-	X
Desmidium sp.	X	-	-	X
Euastrum sp.	X	X	X	X
Euglena sp.	X	X	X	X
Eutreptia sp.	-	-	X	X
Golenkina sp.	X	-	-	-
Micrasterias sp.	X	X	X	X
Micratinium sp.	-	X	-	-
Microspora sp.	X	-	-	-
Oedogonium crispum	X	X	X	X
Oocystis borgei	X	X	X	-
Palmella mucosa	-	-	X	-
Pandorina morum	X	X	-	-
Pediastrum sp.	X	X	X	X
Peridinium sp	X	X	X	X
Phacus curvicauda	X	X	X	X
Plantolyngbya sp.	X	X	-	X
Scenedesmus sp.	X	X	X	X
Selenastrum sp.	X	X	X	X
Spirogyra sp.	X	X	-	X
Staurastrum sp.	X	X	X	X
Tetraedron sp.	X	X	-	X
Tetrastrum sp.	X	-	X	-
Trachelmonas sp.	X	-	X	X
Tribonema sp.	X	-	-	-
Ulothrix sp.	X	X	X	X
Uroglenopsis sp.	-	-	-	X
Volvox sp.	X	X	X	X
Sub-Total	**32**	**24**	**23**	**27**
Blue-Green Algae (Cyanophyta)	**Kpong**	**Dzemeni**	**Kpando-Tokor**	**Yeji**
Anabaena sp.	X	X	X	X
Aphanizomenon flos-aquae	X	-	-	-
Aphanocapsa sp.	X	X	-	-
Coelosphaerium sp.	X	X	-	X
Cylinderospermopsis sp.	X	-	-	X
Gomphosphaeria sp.	X	X	X	X
Lyngbya sp.	X	X	-	-
Merismopedia elegans	X	X	X	X
Microcystis sp.	X	X	X	X
Nodularia sp.	X	X	-	-

Table 3a Cont.

Oscillatoria sp.	X	X	X	X
Planktothrix aghardii	X	X	X	X
Psedanabaena sp.	X	X	X	X
Schizothrix sp.	X	-	-	-
Spirulina princes	X	X	X	X
Synura sp	-	-	X	-
Sub-Total	**15**	**12**	**9**	**10**
Diatoms (Bacillariophyta)	**Kpong**	**Dzemeni**	**Kpando-Tokor**	**Yeji**
Asterionella formosa	X	X	X	X
Ceratium sp.	X	-	-	-
Cocconeis sp.	X	-	-	X
Cyclotella sp.	X	X	-	X
Cymbella tumida	X	X	X	X
Diatoma vulgare	-	X	-	-
Fragillaria sp.	X	X	X	X
Gomphonema africanum	-	X	-	-
Gyrosigma acuminatum	X	-	X	X
Melosira granulata	X	-	X	X
Navicula sp.	X	X	X	X
Nitzschia sp.	X	-	X	X
Phytoconis sp.	X	-	-	-
Pinnularia sp	X	X	X	X
Pleurosigma sp.	-	X	X	X
Rhopalodia sp.	-	X	X	-
Rivularia sp.	-	X	-	X
Sureilla splendida	-	X	X	-
Synedra sp.	X	X	X	X
Tabellaria fenestrate	-	X	X	-
Sub-Total	**13**	**14**	**13**	**13**
Grand Total	**60**	**50**	**45**	**50**

Physico-chemical

The Lake showed narrow differences in temperature from the surface down to 8 m depth in all the sampling sites, indicating no thermal stratification. The differences averaged about 0.8°C. The surface mean water temperatures recorded for the Lake at Kpong were 28.5 and 27.9°C at 100 and 500 m from the shore, respectively. At Yeji, the mean surface temperature was 29.7°C for both sampling sites. The narrow difference in temperature between the surface and the bottom could be attributed to solar radiation which depends on weather conditions and the well mixing conditions of the water. Biswas (1969) and Ofori-Danson and Ntow (2005) also made similar observations in the Lake.

The surface mean pH of the Lake varied between 6.8 (Kpong) to 7.5 (Yeji) at 100 m from the shore, and ranged from 6.9 (Kpong) to 7.7 (Yeji) at 500 m from the shore of the Lake. Generally, the mean pH showed a decrease with depth (Figure 2). For example, at Yeji, mean pH deceased with depth, dropping from 7.7 at the surface to 7.1 at the bottom. The tributaries of the Lake have been reported (FAO, 1971) to have higher pH values (For instance Obosom River, a tributary of the lake, has a pH of 8.7). The pH levels encountered at both surface and bottom were considered suitable for fish growth and productivity, since the best pH values for the survival of fish have been reported to range between 5.0 and 9.0 (Jobling, 1995).

Measuring transparency with secchi disk is said to be one of the most useful ways of showing whether or not a lake is changing through time. Changes in transparency are frequently associated with changes in the amount of algal growth, or the amount of dissolved or particulate materials in a Lake. According to Biswas (1968); Numann (1969) and FAO (1971), the transparency in the Volta Lake is influenced by colloidal suspended particles, colloidal ferric iron and phytoplankton. Transparency measured in this study varied from 100 to 320 cm with a mean of 233 cm at

Table 3b. Algae at stations of study.

Type of Algae	Kpong	Dzemeni	Kpando-Tokor	Yeji
Green Algae	32	24	23	27
Blue-Green Algae	15	12	9	10
Diatoms	13	14	13	13

Table 4. Periods of low and high Chlorophyll-a detections.

Station	High Chlorophyll 'a' detected period	Lowest Chlorophyll 'a' detected period
Kpong	February-March and October-November	June-August and December- January
Dzemeni	July	June
Kpando-Tokor	July	June
Yeji	February-June	July-December

Kpong; ranging from 120 to 206 cm with a mean of 157 cm at Dzemeni; ranging between 58 and 158 with a mean of 119 cm at Kpando-Tokor (Figure 3). Ofori-Danson and Antwi (1994) recorded a transparency value of 220 cm for the Akosombo Gorge area in 1990. At Yeji, Ntow (2003) observed a mean transparency of 50 cm in 1995. Transparency measurements for the period of July 1968-July1970 ranged from 35 to 260 cm with a mean of 134 cm (FAO, 1971). Viner (1990) also recorded a transparency of 50 cm at Yeji. In the present study, transparency measured at Yeji ranged from 20 to 103 cm with a mean of 46 cm. Compared with the previous years, transparency at Yeji had decreased. The reason for this decrease might be progressive increase in colloidal suspended particle as a result of introduction of sediment due to human activities. High transparencies were observed at all stations in the months of March 2007 and January 2008, dry season where suspended matter might have settled unto the Lake bottom. The order of decreasing transparency was Kpong > Dzemeni > Kpando-Tokor >Yeji.

Mean turbidity ranged from 2.14 to 7.38 NTU in the surface water at Kpong, Dzemeni and Kpando-Tokor. A study by the CSIR-Water Research Institute (1999) at these sites recorded a mean range of 1.70 to 6.50 NTU. However, mean value of turbidity observed at Yeji was 80.78 NTU, ranging from 3.9 to 268 NTU (Table 2). The high turbidity levels corresponded with very low transparencies at Yeji. This may be attributable to sediment arising from increased anthropogenic activities which resulted in clay particles in suspension, which was visible in the colour of the water.

The mean DO of the surface water varied between 7.3 and 8.1 mgL^{-1}. Antwi and Ofori-Danson (1993) reported average DO level of 7.78 mgL^{-1} at Kpong. The DO levels were observed to decrease from the surface waters of the Lake to the bottom (Figure 2). Ofori-Danson and Ntow (2005) observed mean DO levels ranging from 8.1 mgL^{-1} (Surface) to 5.2 mgL^{-1} (bottom) at Yeji. The oxygen supply to the Lake is influenced by water turbulence and wind action. The lake could be said to be well oxygenated and therefore could support fish life.

The conductivity values ranged from 53.9 to 83.3 μScm^{-1} in the Lake water with a mean surface conductivity value of 64.0, 62.5, 59.7 and 74.4 μScm^{-1} for Kpong, Dzemeni, Kpando and Yeji respectively. Relatively high values were recorded in Yeji which is riverine and also receive high anthropogenic inputs (Figure 4). When compared with conductivity values of Lake Bosomtwi (mean; 1219 μScm^{-1}) and Weija Lake (mean; 370 μScm^{-1}) in Ghana, Volta Lake has low conductivity. Similar low conductivity values of 68.7 and 84.0 μScm^{-1} were observed at Kpong and Yeji by Antwi and Ofori-Danson (1993) and Ofori Danson and Ntow (2005), respectively. The low conductivity is a reflection of low ionic content of the Lake. The low ionic content had been attributed to two factors: the low solubility of the underlying rocks namely; granite and schist found in the upper catchment area of the Volta basin and the advanced state of weathering of soils in the basin (Wright, 1982). Conductivity is a measure of water saltiness. Low levels natural salts found in water are vital for aquatic plants and animal growth. High levels of conductivity in freshwater can cause problems for aquatic ecosystems and complicate human uses.

A striking feature of the constituents of the Lake is the nutrient level which was generally low. Mean nitrite-nitrogen level varied between 0.007 and 0.029 mgL^{-1} at all sites. Nitrate-nitrogen ranged from 0.29 to 1.70 mgL^{-1} at Yeji, while mean ammonia-nitrogen varied from 0.26 to 1.30 mgL^{-1}. Orthophosphate levels were from 0.19 to 0.30 mgL^{-1}.

Phytoplankton

A total of 73 algal taxa were encountered in the present

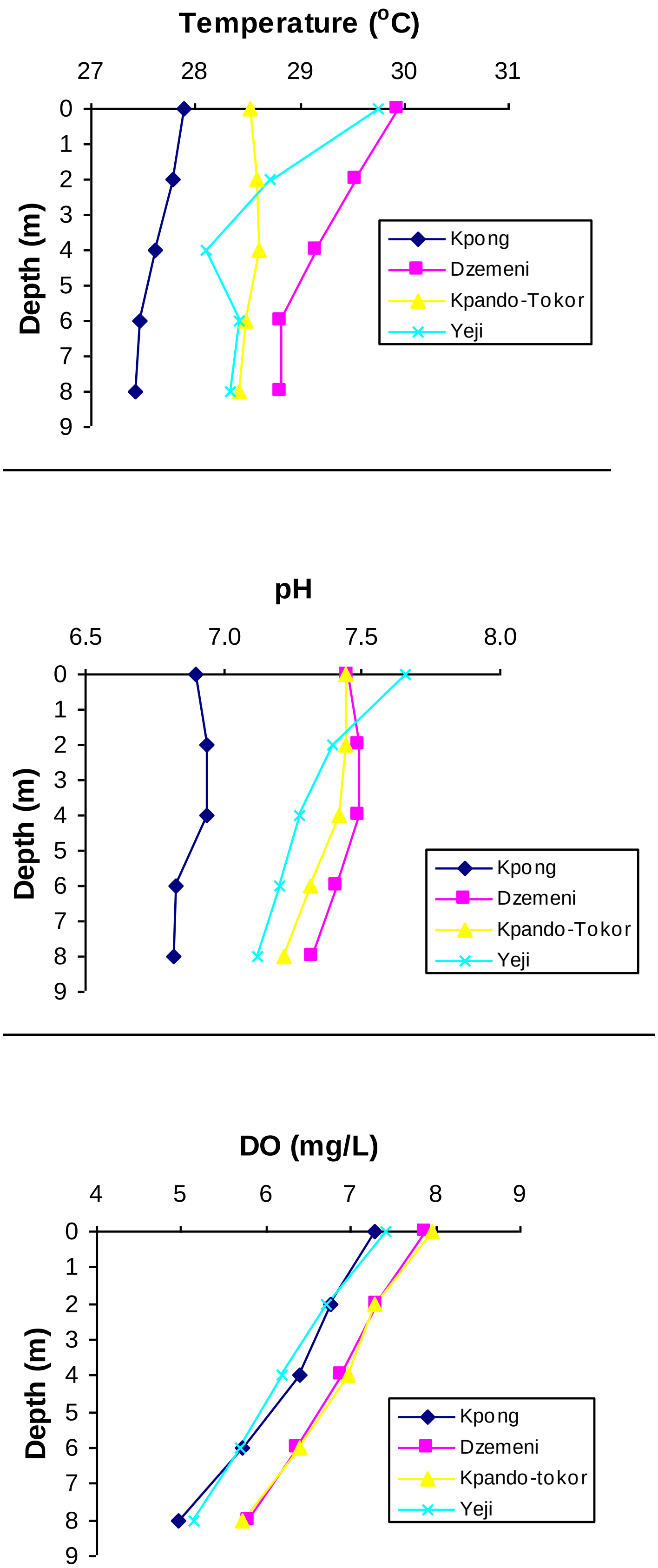
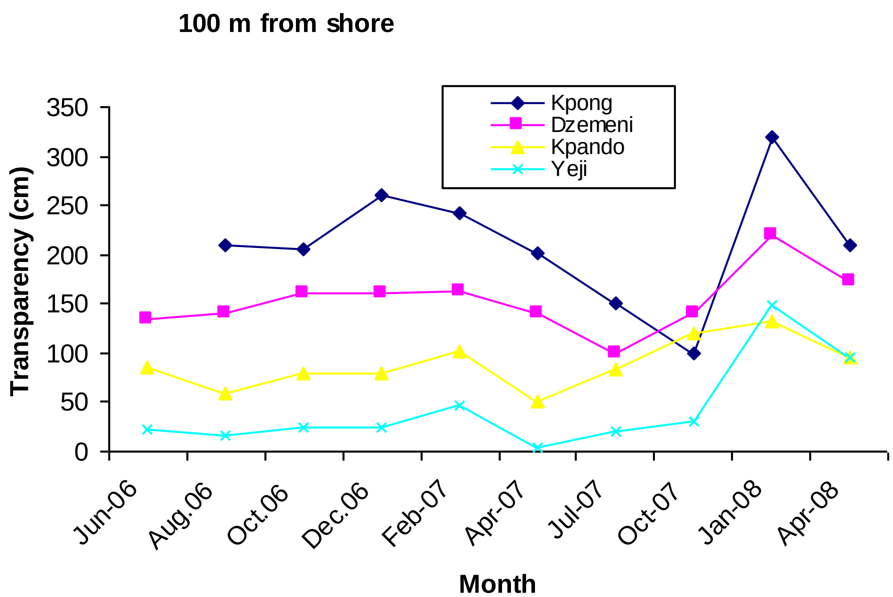


Figure 2. Mean temperature, pH and DO profiles of Lake Volta.



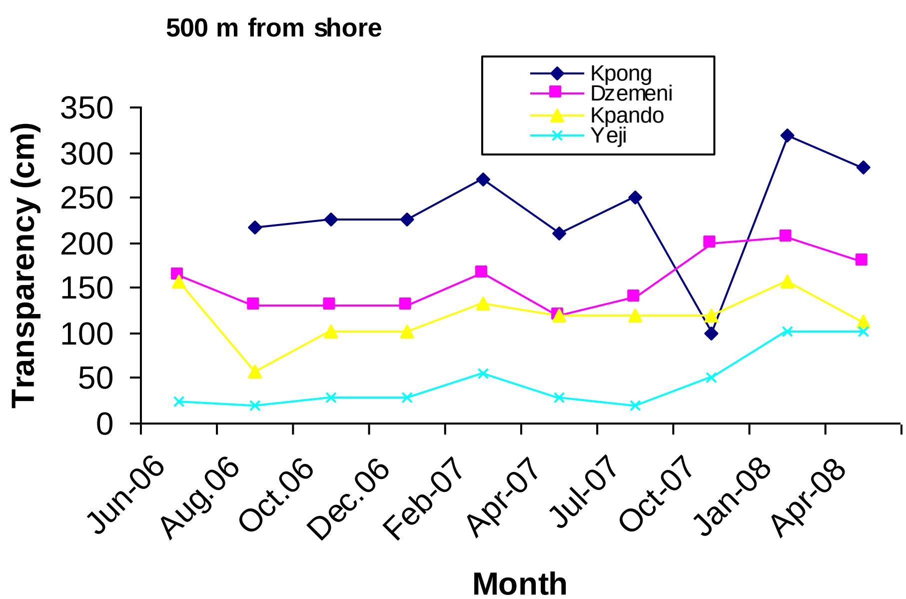


Figure 3. Monthly transparency variation.

study on the Volta Lake. These include 37 Green algae (Chlorophyta), 50.68%; 16 Blue-Green algae (Cyanophyta) 21.92% and 20 Diatoms (Bacillariophyta) 27.40% (Table 3a). Thus abundance of Green algae is greater than Blue-Green algae which in turn are greater than the Diatoms. The algae categories and their distribution among the four study stations are shown in Table 3b. The table shows that the northern lake station of Yeji was richer in Green algae (27 taxa) compared to the two southern stations of Dzemeni and Kpando-Tokor (24 and 23 each) which were similar in green algae diversity. The Blue-Green algae and the Diatoms were about evenly occurring at the three stations on the lake. The Kpong station, located below the main Volta Lake was richer in Green and Blue-Green algae compared to stations on the main lake.

Of the total 37 Green Algae, 17 (45.95%) were common to all the stations. Nine of the Blue-Green Algae species (56.25%) were also common to all stations, while 6 of the 20 Diatom species (30.0%) were common to all stations. At Dzemeni and Kpando-Tokor stations (Stratum II and III) in the south, Green Algae occurrence was high almost throughout the year with peaks in about February, August

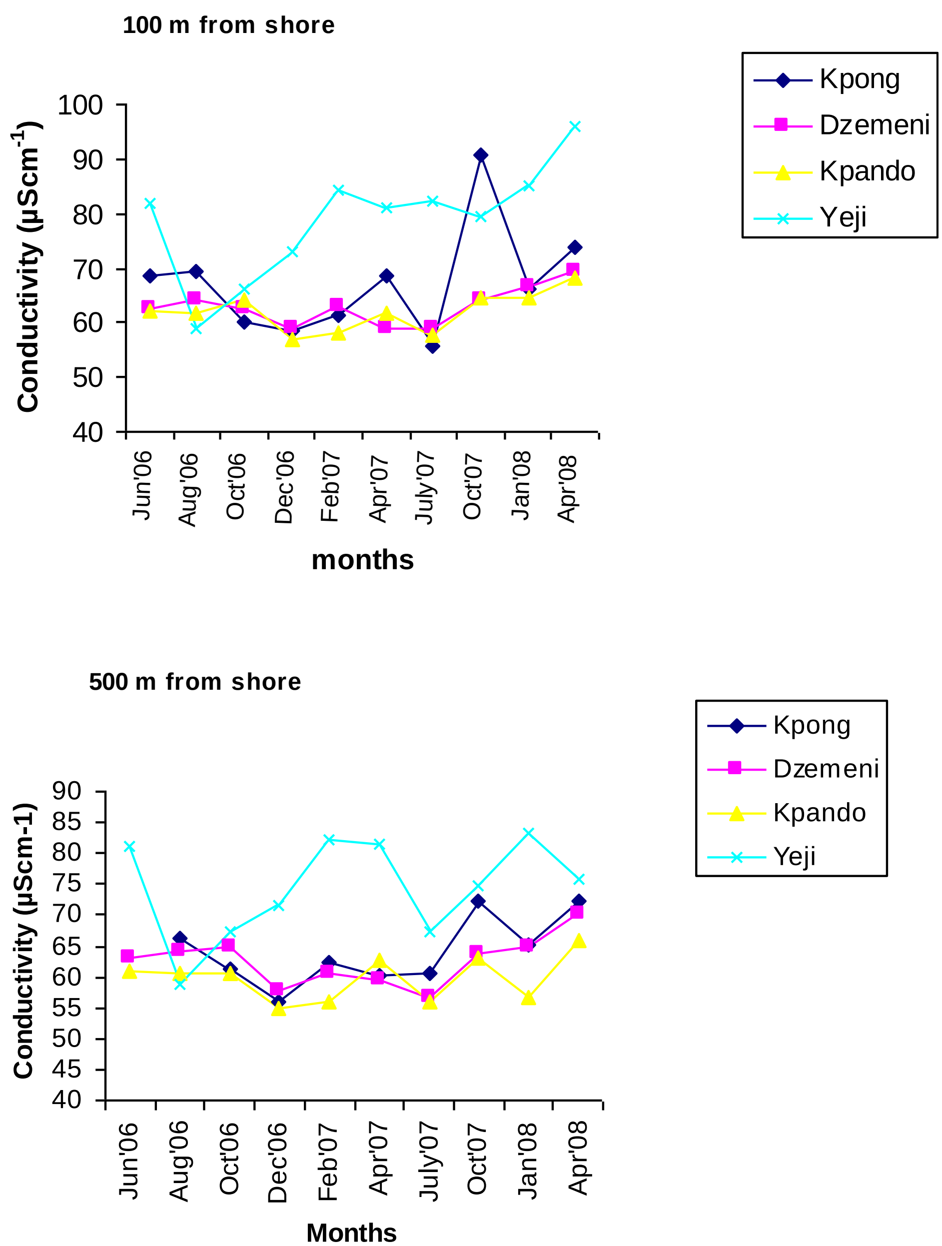


Figure 4. Monthly conductivity variation.

and December. Yeji in the north (Stratum VII), had Green Algae peak in June and December. Blue-Green Algae showed peak in August at Dzemeni but was almost always low at Kpando-Tokor. Yeji had the highest Blue-Green numbers in December.

Limited work has been carried out on estimating primary productivity through the composition and abundance of phytoplankton and zooplankton in the Volta Lake. Work done by Viner (1969, 1990) indicated that phytoplankton were uniformly distributed in the water column at Ajena, in the southern part of the reservoir, but were limited in abundance further north at the Afram confluence, Kpando and Kete Krachi. Bacillariophyta were more dominant at the southern stations, while cyanophytes were dominant further north. Chlorophyta were more abundant north of Kpando, while along the Oti River arm of the reservoir, north of Kete Krachi, cyanophytes were dominant.

Primary productivity fluctuations in temperate lakes are more clearly defined and connected to seasons than in the tropics (Feresin et al., 2010). Primary production can be much higher in tropical lakes due to the direct effect of the temperature, under nutrient saturation (Lewis, 1996),

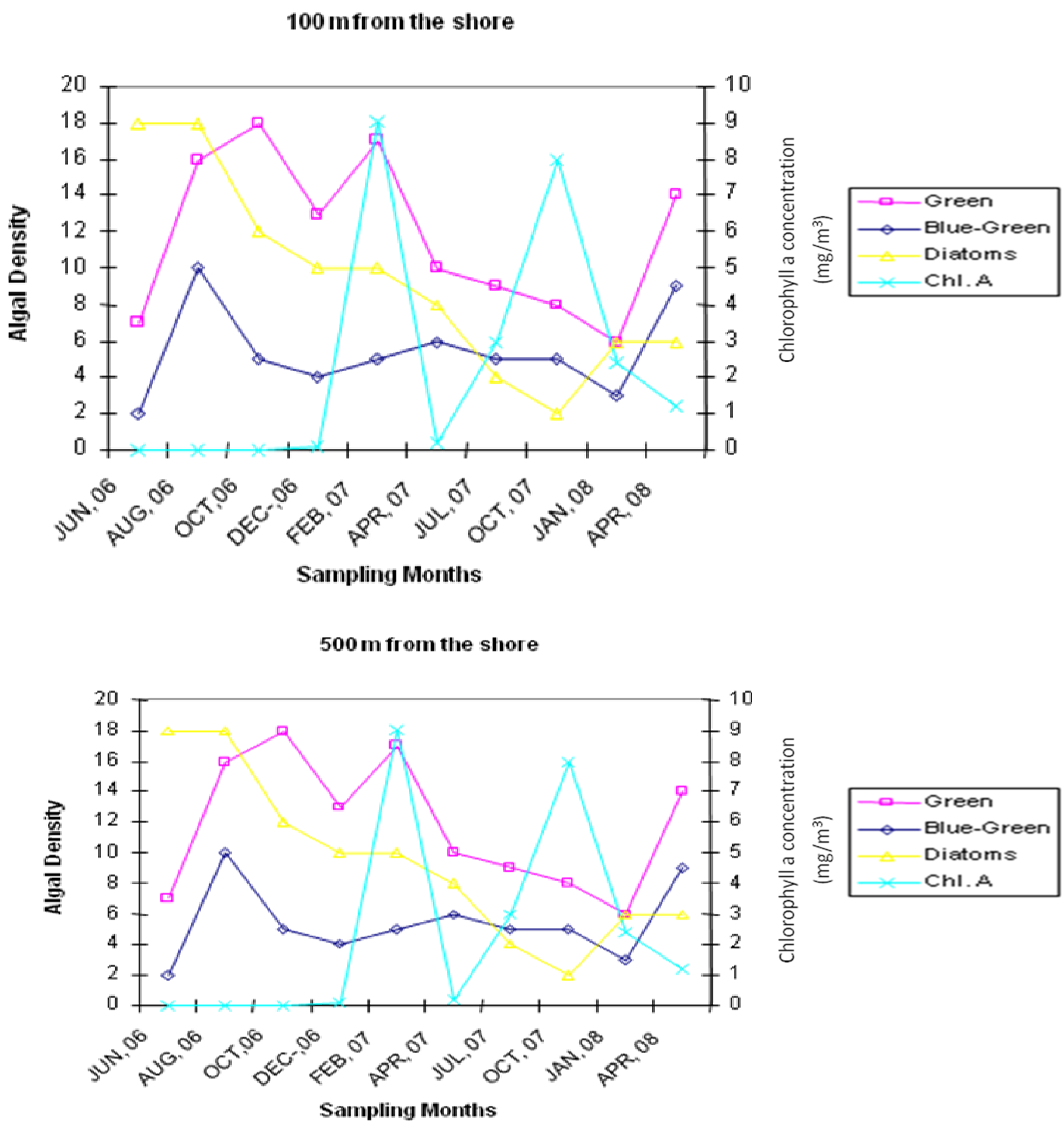
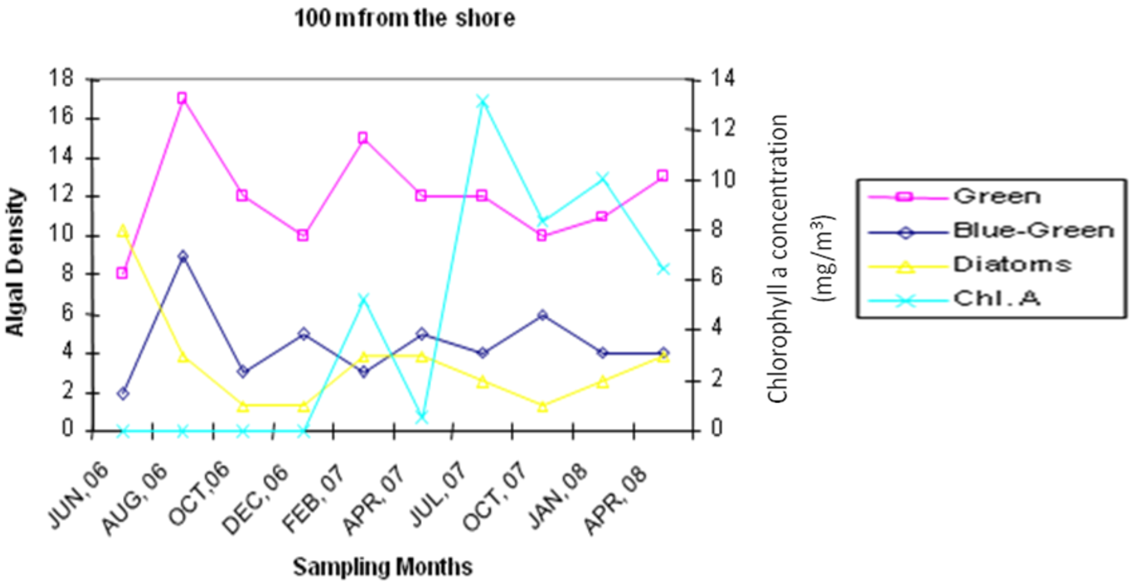


Figure 5A. Algae and Chlorophyll-a concentration at Kpong.

reaching values 2 to 3 times higher than in temperate lakes (Lewis, 1996; Amarasinghe and Vijverberg, 2002). The complex dynamics of the mixed layer and the higher metabolic rates in tropical lakes speed up the return of nutrients to the euphotic zone (Lewis, 1996). The basic controlling factors of primary production are light and nutrients, varying their relative importance in the ecosystems according to their dynamics. Fish productivity is enhanced through the increase in natural food materials in the form of plankton biomass resulting from the nutrients, as well as the direct consumption of the spilled food and possibly organic manure.

The influence of abiotic factors, such as light, temperature, and hydrology is more evident on the temporal fluctuations of productivity rates in the lake, when compared to that of biotic factors. The temporal and vertical distribution of primary productivity rates is directly or indirectly related to the thermal behaviour of the lake. Although the lake circulates irregularly during the year, a period of more stable stratification is evident in the



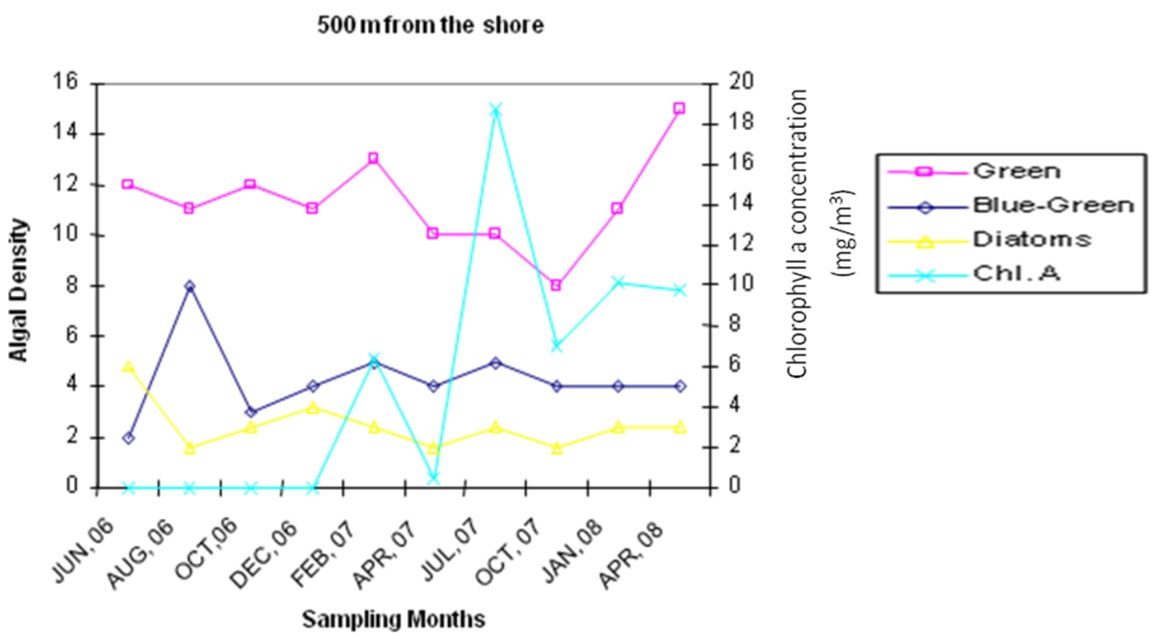


Figure 5B. Algae and Chlorophyll-a concentration at Dzemeni.

warm-wet season, particularly from June to August.

In summary, it can be confirmed as evidences point to physical and chemical factors as the preponderant factors influencing the primary production of the phytoplankton in the Lake Volta. The primary productivity, thus, has a close relationship to the thermal behaviour of the lake, whose features is connected to its depth and wind strength. Also, the presence of the algae throughout the year is in conformity with the fact that optimal conditions of temperature, sunlight and other abiotic factors exist in the Lake Volta Basin which is located in the tropics.

Chlorophyll 'a'

Figure 5 shows recorded chlorophyll 'a' concentrations (mg/m^3) and densities of Algae groups in water samples obtained at 100 and 500 m locations at the four stations.

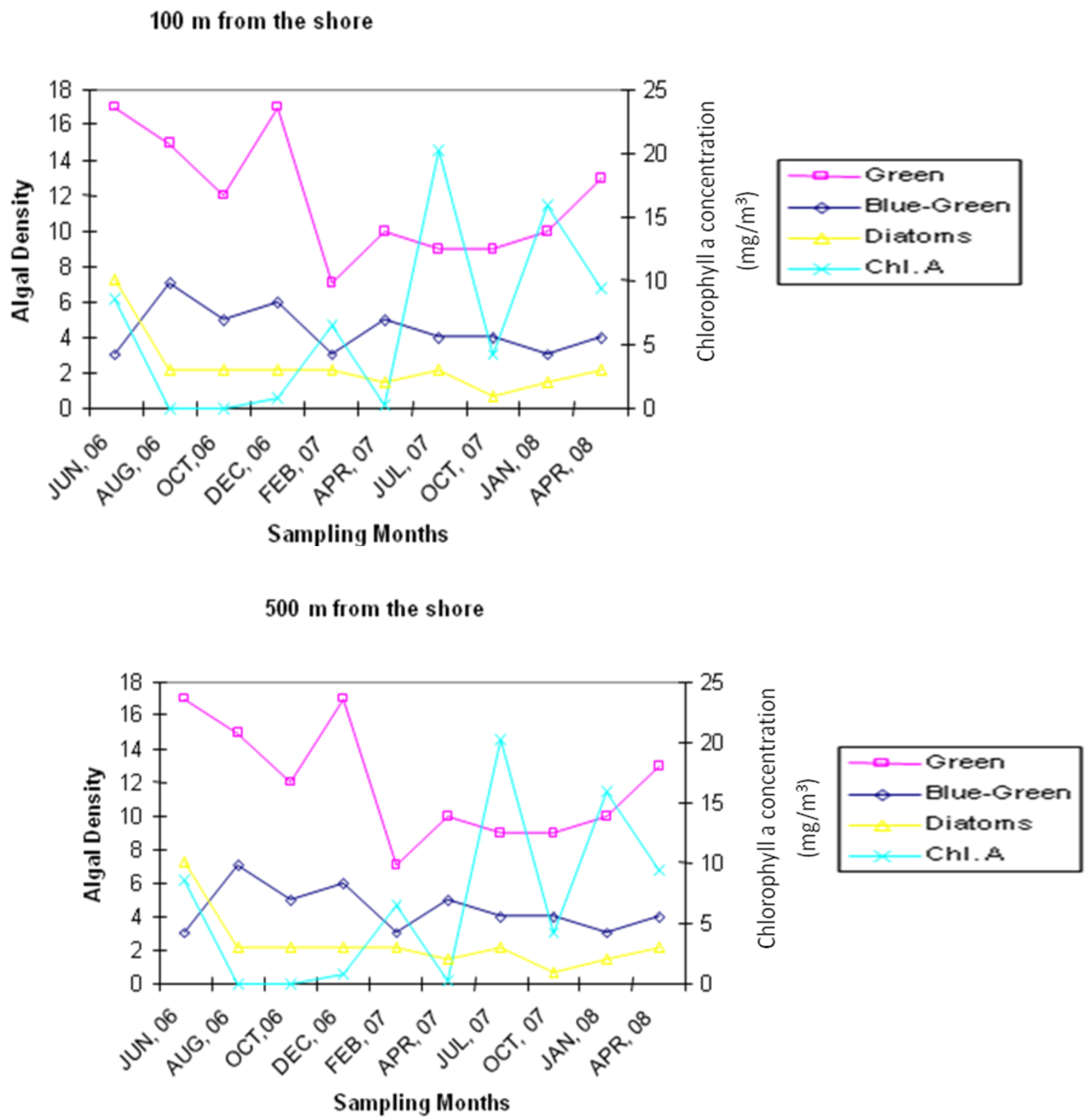


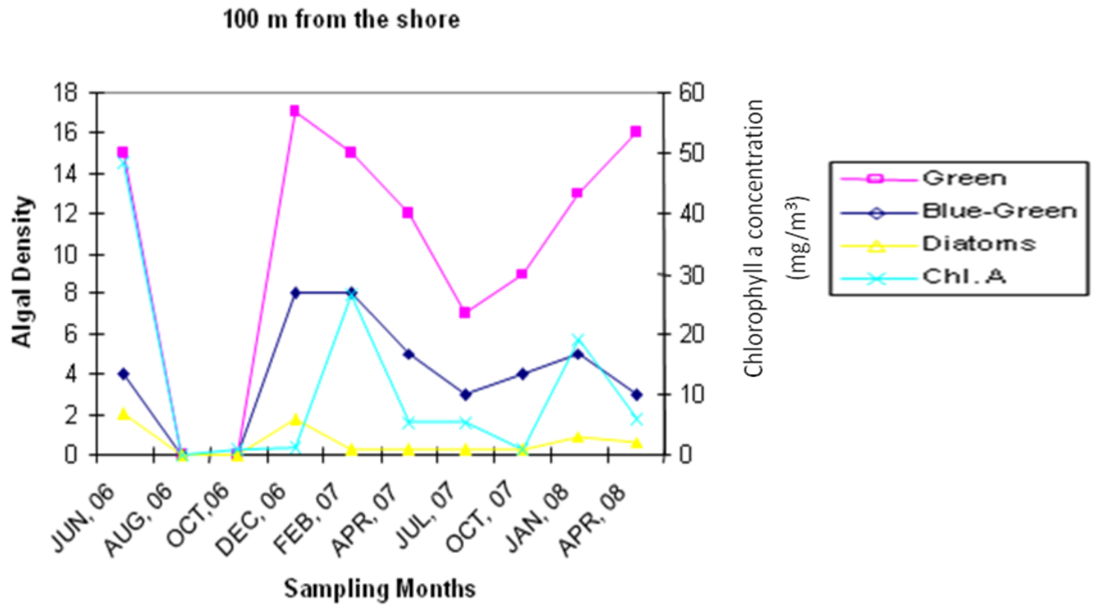
Figure 5C. Algae and Chlorophyll-a concentration at Kpando-Tokor.

Reference to concentrations of chlorophyll 'a', the figures briefly suggest the following:

At the Kpong station, the period of highest chlorophyll 'a' detection in the water samples were about February-March and October-November. The lowest detection months were June-August and December-January.

At Dzemeni in Stratum II, the period of highest detection of chlorophyll 'a' was July (about 19 mg/m^3) followed by a three month period January-April, during which a level of about 9-10 mg/m^3 detection was maintained. Lowest chlorophyll 'a' detection period at Dzemeni was June, August and December. At Kpando-Tokor (Stratum III), the pattern of chlorophyll 'a' concentrations detection were comparable to what was observed for the Stratum II (Dzemeni station). At the Yeji station, about February till June was the period of high detection of chlorophyll 'a'. From about July till October was when low detection was recorded. These fluctuations in chlorophyll a concentrations follow the rainfall pattern of the areas, that is, during the rainy season when high amounts of nutrients are discharged into the reservoir from fertilizer run-offs from adjoining farmlands.

Chlorophyll *a* is considered the principal variable to use as a trophic state indicator (Boyer et al., 2009). There is generally a good agreement between planktonic primary production and algal biomass, and algal biomass is an excellent trophic state indicator (Vollenweider and Kerekes, 1982) Chlorophyll a concentration indicates the trophic level of the lake. It is also a measure of the phytoplankton production potential. Though all autotrophic



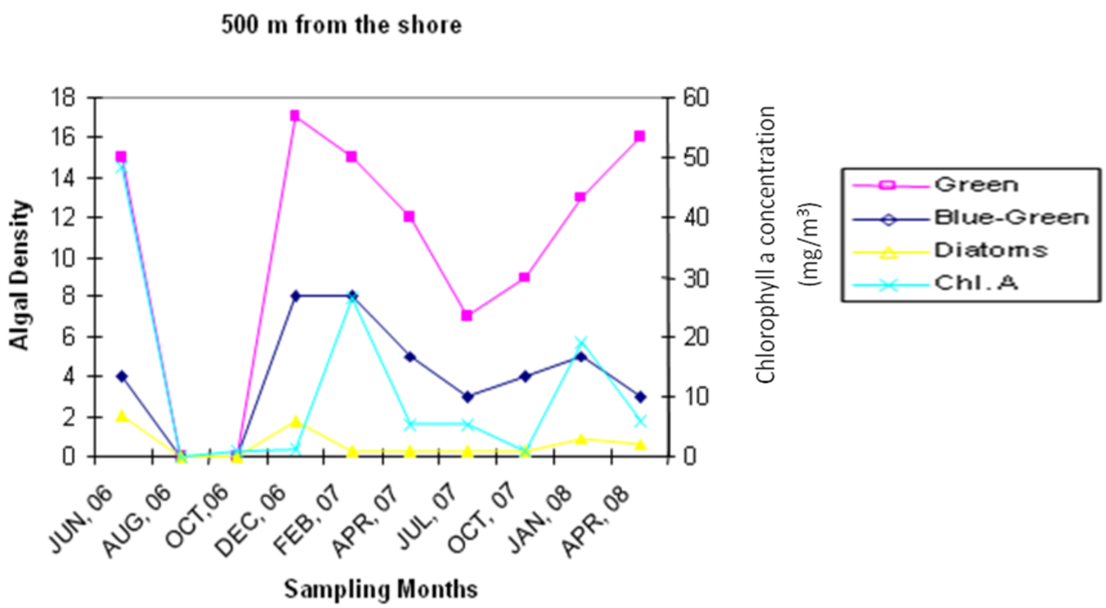


Figure 5D. Algae and Chlorophyll-a concentration at Yeji.

algae contain chlorophyll, the chlorophyll concentration need not be directly correlated with biomass; but rather, their relationship is affected, for instance, by illumination, nutrient concentrations and the species composition of the phytoplankton assemblage. All phytoplankton, prokaryotic and eukaryotic, possess chlorophyll *a* as the central pigment of photosynthesis. Therefore, chlorophyll *a* lends itself as a measure of phytoplankton biomass. The amount of chlorophyll *a* in a volume of water is proportional to the present phytoplankton biomass, and due to the simplicity of performing this measurement, chlorophyll analyses are the most common measure of phytoplankton abundance.

According to Table 5, large reservoirs can be placed in one of five categories, using fish production or benthic production levels as criteria. On the basis of Table 5, Volta Lake, having a yield of 42–52 kg/ha/yr, is mesotrophic-eutrophic, rather than the oligotrophic that might be assumed based on the nutrient content (Antwi, 1990). The possible reconciliation of this paradox was outlined by Obeng-Asamoah (1977). The essential nutrients released by the breakdown and mineralization of the organic load are immediately picked up by the algae and *Ceratophyllum.*

Table 5: Classification of reservoirs by fish production and by benthic production

Trophic state of reservoir	Fish production (kg/ha/year)	Benthic biomass production (kg/ha)
Oligotrophic	2–7	<15
Oligotrophic-mesohumic	7–15	15–30
Mesohumic-mesotrophic	15–30	30–60
Mesotrophic-eutrophic	30–60	60–120
Eutrophic	>60	>120

Source: FAO CIFA Technical Paper (1995)

Conclusions

The study revealed that temperature, dissolved oxygen and pH decreased with increasing depth. The average values of temperature, dissolved oxygen and pH at all sites was considered quite comparable to what have been reported from similar areas in previous studies and were suitable for normal fish life activities.

Low turbidity values corresponded with high transparencies at Kpong, Dzemeni and Kpando-Tokor. However, at Yeji, turbidity values were relatively high as the transparencies recorded were low due to suspended particles as a result of the introduction of sediment arising from anthropogenic activities.

The generally low concentrations of the nutrients coupled with sufficient oxygen throughout the year at all depths suggest that the Volta Lake is not eutrophic but oligotrophic. However, based on fish and benthic production, the Lake can be classified as mesotrophic-eutrophic.

Generally, the productivity of the Volta Lake is high but fluctuates with the rainfall regime of the basin. That is, productivity is high in the rainy season and low in the dry season. It can also be said that, productivity is higher (higher density and abundance of phytoplankton) in the northern part (Strata vi, vii and viii) than in the southern part (Strata i-v).

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