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DETERMINATION OF THE PHYSICO-CHEMICAL AND PRIMARY PRODUCTIVITY LEVELS OF THE OWABI LAKE, GHANA

Arkoh Martin Abed*, Anning Alexander

Theoretical and Applied Biology Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Corresponding author: maarkoh.sci@knust.edu.gh

ABSTRACT

The primary productivity of water bodies is important in considering the health and resilience of aquatic ecosystems. Primary productivity depends on free oxygen and the chlorophyll 'a' contents of a water body. The study determined the primary productivity and chlorophyll 'a' level of the Owabi lake to serve as primary data upon which further studies could rely on. Twenty six sites along the margins of the lake were mapped with GPS and 5.0 meter x 5.0 meter quadrats laid. Within each of the demarcated sites, some physico-chemical parameters were measured by standard procedure on the field and in the laboratory, and 100ml of the water sample was sent to the laboratory for chlorophyll 'a' determination. The dissolved oxygen concentrations in the bottles were measured with an OAKTON DO multimeter and the physico-chemicals, with a multi-purpose field meter. Within each quadrant, three dissolved oxygen measurement bottles, representing oxygen levels during day period, dark period and a control, were laid 5.0 cm depth into the water body overnight. The physico-chemical parameters recorded mean values that were lower than the WHO limits with $p=0.553$ indicating non-significant differences within the studied sites. The nutrients values were low but increased in concentrations at the lower portion of the lake. The chlorophyll 'a' indicated highest value (53.71±2.06 µg/L) at the lower part of the lake, while the lowest (34.09±0.99 µg/L) was recorded at the upper portion indicating eutrophic status. The Net Primary Productivity (NPP) was higher at the middle portion with 5.20±0.05mg/L, while the oxygen production in the dark (respiration) indicated 4.33±0.32mg/L at the lower part. The highest Gross Primary Productivity (GPP) value of 18.74±0.16mg/L/hr was found at the lower part of the lake with free oxygen registering 0.67±0.07mg/L in the middle portion. Though, the physico-chemical values were within the WHO acceptable ranges, the lower and inadequate levels of the NPP and free oxygen with a hyper-eutrophy in chlorophyll 'a' concentration render the lake unhealthy and unsustainable for the life of aquatic organisms.

Keywords: aquatic ecosystem, resilience, primary productivity, physico-chemical

INTRODUCTION

Wetland is a lowland area mostly saturated with water. It is a mixture of water and vegetation, and serves as a habitat and buffer zone against sediments, macro-pollutants and nutrients build up in lake (Ramser Convention 1971; IUCN 1992 & Ramser Convention Bereau 2006).

Primary productivity of surface waters is an important aspect considered in environmental health and ecology of aquatic ecosystems. Increase in productivity and consequently high fish yield are the major characteristics of an aquatic environment with adequate free oxygen (Ryther and Yentsch 1991). Primary productivity refers to the rate at which energy is produced and stored by phytoplankton and macrophytes through the process of photosynthesis. These aquatic organisms use energy from the sunlight and nutrients to produce organic substances which could be used and also, stored as food (Wondie et al., 2007). Primary productivity is influenced by the physico-chemical and biological characteristics of an aquatic environment, and these could be affected negatively by anthropogenic activities that could lead to the deterioration of the surface water quality and low population of most aquatic organisms within the aquatic environments (KDHE 2001).

Owabi lake is within the protected wetland and forms the only inland Ramser site in Ghana, and it is fed by four rivers; Punpunase, Sukubriso, Akyeamponene and Owabi. The rivers run through urbanized and agricultural towns before emptying into the lake (Badu et al 2013; Akoto, et al 2017), which may tend to transport solid and dissolved pollutants into the water body. There is no information on the primary productivity of the Owabi lake that was created by the damming of the River Owabi and its smaller tributaries in 1928 to serve as the source of potable drinking water for Kumasi Metropolis in Ghana (Akoto et al 2017). The study of primary productivity and free oxygen of the Owabi lake would be fundamental, and help determine the resilience and sustainability of the water body.

MATERIALS AND METHODS

Sampling site

The Owabi lake is located in the Owabi Ramser Reserved wetland within the Kumasi Metropolis and the Atwima-Nwabiagya District of the Ashanti Region (Fig 1A). The wetland covers an area between 06°47’3.32”N 001°37’53.4”W and 06° 41’52.3”N 001°44’0.81”W.

Sampling techniques

Twenty six sites were selected through purposive sampling around the peripheries of the lake, and with two in the middle (Fig 1B). Of the twenty six sites, sixteen were laid within the upper portion of the lake (06°43’6.04”N 001°40’28.1”W) where the feeding rivers enter the water body, and eight sites at lower portion (06° 42’08.6”N 001°41’49.2”W) where the dam is located (Fig 1B).The sampled sites were indicated with buoy markers for consistency on all sampling occasions by the use of canoes and research assistants. The GPS coordinates of the sites on the lake were taken with a handheld GPS reader instrument (Garmins Trex 10 model) with an accuracy of 15 meters at 95% of the time. Sampling was performed once a month for a three month period.

Physical parameters measurements of the Owabi lake

Measurement for physical parameters was performed through in-situ process on the field. Light intensity, temperature and total dissolved solids were measured with a portable Oakton Waterproof Field Meter. The probe of the instrument was immersed into the lake at the depth of 5.0 cm at each sampling site and the readings for the measuring parameters taken.

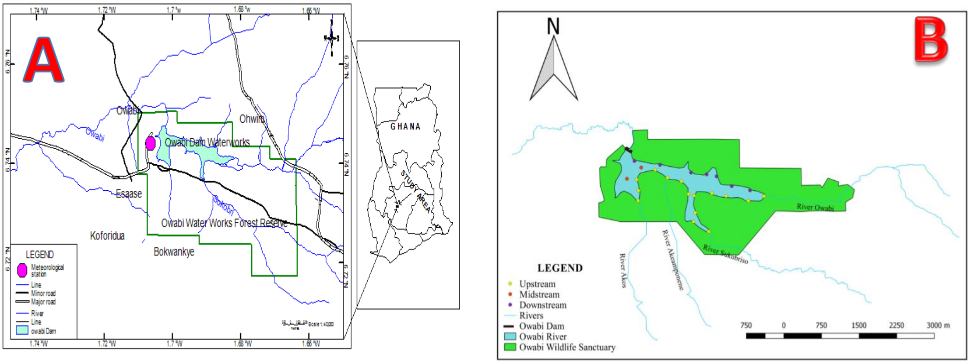

Figure 1: Map showing the location of the Owabi lake in the Ashanti Region (A), and the sampling sites for primary productivity determination (B).

Chemical parameters and chlorophyll a levels of the Owabi lake

Chemical and chlorophyll 'a' analysis were performed through ex-situ processes. Water samples from each of the twenty six sites were collected into 100 ml sampled bottles. At each site, the bottle was cleaned and then, filled with some of the water to the brim. A stopper was used to cork the bottle, and then the sample inserted into an ice container at 0°C. These were kept in ice containers and transported to the KNUST Civil Engineering laboratory for chemical and chlorophyll 'a' analysis by the Hach method (for nitrite-nitrogen), PhosVer 3 method (for phosphate) and Spectrometric method (for chemical and chlorophyll 'a').

Procedure for measuring dissolved oxygen levels in the Owabi lake

The primary productivity of the lake was determined by assessing the levels of oxygen concentration in dissolved oxygen bottles, which are made up of a light (daylight oxygen production), dark (oxygen production at night) and control bottles with an Oakton DO6+ dissolved oxygen meter which has an accuracy of ±0.2%. The measurements of oxygen levels in these bottles indicate the net primary productivity and respiration of photosynthetic organisms in the water body during the day and in the night.

Three special DO bottles were immersed into each demarcation of the 26 sites on the lake at a depth of 5.0cm secured with a floating cork. The bottles were filled with some of the water to the brim, with the exception of one bottle that was supposed to serve as control, and immersed into the lake for the 24hr incubation period. Thus, a total of seventy eight DO bottles were utilized in the DO assessments.

The bottles were left overnight in the water and at the end of the 24 hours period, the bottles were removed and assessed for dissolved oxygen levels with the Oakton DO6+ meter. The decrease in dissolved oxygen concentration in dark bottles over the time period depicted the measure of the respiration because photosynthesis does not occur in dark bottles. However, the light bottles measured an increase in dissolved oxygen due to the occurrence of both respiration and photosynthesis. The decrease or increase in dissolved oxygen in the dark and light bottles with reference to the control bottles over the 24hr period give a measure of net and gross primary productivity of the lake. The difference in the dissolved oxygen measured over time between the light and dark bottles indicated the total amount of free oxygen in the water.

Formula:

Gross primary productivity = Net primary production + Respiration

Free oxygen = Net primary productivity - Respiration

Statistical analysis

A one-way ANOVA and correlation analysis to indicate the variations in levels of the parameters measured and their conformity with each other were employed from the Genstat_01 model statistical package and used to analyze the mean values obtained from the study at a significance level of 0.05. Subsequently, the Least Significant Difference (LSD) and Standard Error Bars were used to ascertain differences between means at α=0.05.

Figure 2: The edge of the lower part of the lake is not shaded with tree covers (A), whilst the upper part is shaded by tree covers (B).

RESULTS AND DISCUSSION

Physico-chemical parameters and nutrient levels of the Owabi lake

The physical parameters mean values obtained from the measurements showed lower values and were below the World Health Organization guideline limits (WHO 2014). The maximum mean temperature of 29.17±0.10°C was recorded at 06° 42'08.6"N 001°41'49.2"W (lower part of lake) and this could be due to the direct impact of sun energy on the water as that part of the lake has no tree cover to block the sun rays from reaching the water (Fig 2A). The upper portion of lake recorded the lowest temperature of 29.03±0.12°C (Table 1) as a result of the shade on the water body from the trees (Fig 2B). The values were within the WHO acceptable range for temperature (25.0°C-30.0°C). Light intensity followed similar trend and explanation except that the highest value was recorded at the central portion of the lake since that portion has the most direct impact of the sun as a result of no plant cover. A lower light intensity value of 890x 10^3 Lux, that was inadequate and below the WHO limit of 1.0x 10^4Lux was recorded at the upper portion due to the shading of the tree canopies (Fig 2B).

The upper part of the lake (06°43'6.04"N 001°40'28.1"W) recorded a total dissolved solid (TDS) of 259.86±1.10 ppm, with the middle portion registering the lowest value of 227.75±1.30 ppm. The highest value of the

TDS at the upper portion could be attributed to the eroded and leached substances being brought to the lake by the four feeding rivers. However, the moderate levels of the TDS could influence osmoregulation in freshwater organisms by increasing the solubility of gases like oxygen, and also reduce eutrophication in aquatic ecosystems (Carpenter et al 2001; Hadade and Mull 2003). The differences in the values of the physical parameters were found to be significant (p=0.048).

The chemical parameters values obtained indicated higher values at the lower part of the lake (06° 42'08.6"N 001°41'49.2"W) while the lower values occurred at the upper part of the lake (Table 1). The mean pH values for the lake water sampled ranged between 7.24± 0.16 - 7.83± 0.24, and were within the acceptable WHO limit of 6.5-8.5 (WHO 2014). The highest mean pH was recorded at the lower portion and the lowest at the upper part (Table 1). Low pH could be attributed to the presence of effluents and leachates from dumpsites located in the fringing urban towns (Boadi et al 2018). Kakari et al (2013) recorded similar pH range of 6.8-7.7 in an earlier work on the Volta lake in Ghana. Chlorine (Cl^-) ions also ranged between 106±1.08 mg/L - 80.94±0.16 mg/L. These values were very low and below the WHO limit of 250 mg/L. The alkalinity measured deferred from the usual trend by recording its highest value of 116.05±0.08 mg/L at the upper part of the lake (Table 1). The leaching of substances from the adjoining farms by the feeding rivers into the lake could be responsible for the value obtained at the upper part of the lake. The variations in the mean values obtained from the chemical analysis was however non-significant at 0.55.

Nutrient levels of the lake obtained indicated varied trend. The phosphate level was higher in upper part of the lake with 187.43±35.28 mg/L and the lowest of 101.06±16.44 mg/L in the middle portion, while nitrite-nitrogen recorded the highest value at the lower part of the lake while the middle portion showed the lowest value of 320.63±6.51mg/L (Table 1). Phosphorus is one of the essential nutrients for plant growth though high phosphorus concentration could lead to dense algal populations and eutrophication in water bodies (Beadle et al 2015). It could also be used to measure productivity levels in water bodies. Though, the phosphate indicated lower levels below the WHO guideline limit of 250mg/L, that of the nitrite-nitrogen recorded higher value above the WHO guideline of 100mg/L. The values for the nitrogen obtained could be as a result of the leaching of nitrogenous substances from a bush-burning activity that happened earlier on the adjoining forest cover (Badu et al 2013). The relative heavy weights of the nutrients could, also cause them to sink to the bottom of lakes which may lead to a decrease in their concentrations at the middle part of the lakes (Hood et al 2003).

Bruce (2008) and Ando-Mensah et al (2016) recorded high concentrations of phosphorous and nitrogen in an earlier study due to the surroundings of the Owabi River being devastated by previous bush fires that reduced the tree covers which might have shed their leaves to enrich the soil with nutrients. The phosphorous and nitrogen recorded in this work were moderate because the trees might have recovered from the effects of the forest fires and nutrients in the soil might have been leached already into the water body.

Table 1. Mean physico-chemical and nutrients levels of the Owabi lake

Measured Parameters	Sampled Zones			WHO Limits
	Upper Portion	Middle Portion	Lower Portion	
Temperature/ °C	29.03±0.12	29.10± 0.66	29.17±0.10	25.0-30.0
Light intensity/ lux	890x 10^3	1.28x 10^4	1.26x 10^4	1.0x 10^4
TDS / ppm	259.86±1.10	227.75± 1.30	232.50±1.12	500
pH	7.24± 0.16	7.47± 0.64	7.83± 0.24	6.5 – 8.5
Cl^- /mg/L	80.94±0.16	96.08± 0.11	106± 1.08	250
PO_4^{3-}/ mg/L	187.43±35.28	101.06±16.44	132.18±12.18	250
NO_2-N_2/ mg/L	460.83±21.22	320.63±6.51	548.09±10.52	100
Alkaline/ mgL	116.05±0.08	88.68±0.06	111.34± 0.06	150

Primary Productivity

Chlorophyll a levels in the Owabi lake

Chlorophyll ‘a’ is a predominant photosynthetic pigment found in algae and could be used to estimate algal biomass or the trophic conditions in a lake or reservoir (USEPA 2022). The highest value of chlorophyll ‘a’ concentration was recorded in the lower portion with 53.71±0.06μg/L. with the lowest value of 34.09±0.99 μg/L at the middle part (Fig 3). The difference in values was not significant and indicated the presence of more green pigment producers at the lower portion than the upper part where the feeding rivers enter the lake. The Owabi lake could be considered as being eutrophic (26-75mg/L) with reference to Horne and Goldmann’s (1994) classification. The presence of adequate oxygen is vital to the life of fishes. The values obtained were above the acceptable range of 2-6μg/L for mesotrophic water bodies (kakari et al 2013). Awotwi (2018) studied the phytoplankton quality of lake Bosomtwe and values of 13.52 μg/L for wet season and 7.26 μg/L in the dry season were obtained. These values were well below that obtained in this work, and may be attributed to the fact that lake Bosomtwe is a closed lake with no river outlets. Phytoplankton population is thus, high at all times.

The lower portion of the lake experienced higher sun energy due to its exposure to direct sunlight because of lack of tree cover (Plate 2a). Adequate sunlight and nutrients promoted the presence and high growth of plants as compared to the upper portion that had tree canopies covering the sample zones (Plate 2b). Chlorophyll a has been predicted to be greatest under high N+ and P+ conditions (Filstrup and Dowing 2017), and this confirms the positive correlation (+0.33) found between chlorophyll ‘a’ and N_2 concentration in this study. Phosphorus showed a negative correlation of -0.87 with chlorophyll ‘a’ (Table 3). Though, Gitelson et al (2016) and Papagaorgiou et al (2009) had indicated earlier that chlorophyll ‘a’ was more efficient in photosynthetic processes under high nutrient levels, this work showed that chlorophyll ‘a’ could be more efficient under low phosphorous concentration (Table 3).

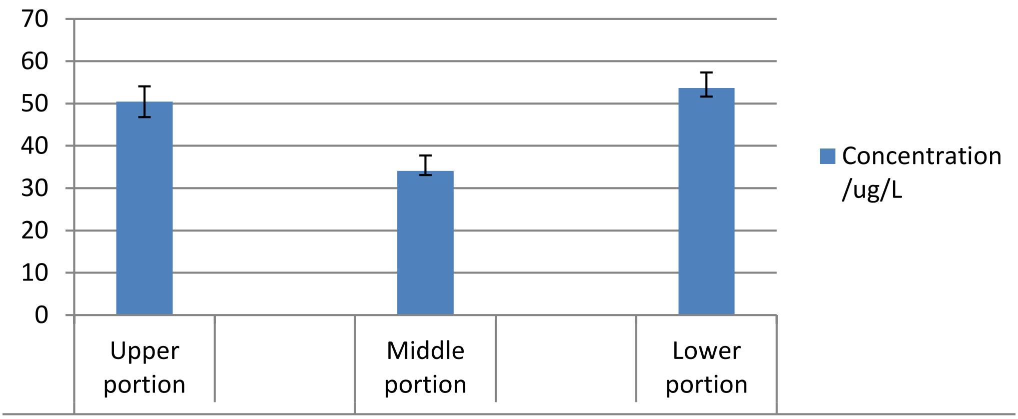

Fig. 3 Chlorophyll a levels in the Owabi lake

Dissolved oxygen (DO)

Dissolved oxygen in the DO bottles indicated a different trend in concentration to that shown by the Environmental factors in Table 1 and the chlorophyll 'a' levels in Fig 3 where concentration of some chemicals lowered in the middle part of the lake. The middle portion recorded the highest DO of 5.20±0.05mg/L in the light bottles while the lower part recorded the highest value of 4.33±0.32mg/L for night DO production/ respiration (Table 2). Dissolved oxygen (DO) gives an idea about the biological and biochemical reactions that occur in aquatic environments and the high DO value for the middle portion, indicated lower biological activities that tend to use oxygen in the water at the middle portion. The DO values obtained were below the WHO recommended range of 6.5-8.0mg/L, and the mean value of 4.62±0.01mg/L indicated insufficient oxygen in the lake.

Free oxygen concentration in the Owabi lake

Free oxygen is the oxygen freely available in the water body for the use of living organisms, and is an attribute of the resilience potential of the water body. Free oxygen in the Owabi lake showed a very high value of 0.67±0.07mg/L at the middle portion as against the upper and lower portions (Table 2). However, these values were lower than the WHO range of 4-15mg/L and the mean value of 0.40±0.03 for the water body was far below the WHO accepted range for water bodies and indicate an unhealthy environment to the living organisms in the lake. A study on the Volta lake in Ghana recorded an oxygen range of 7.3-8.1mg/L (Kakari et al 2013), which was well above that obtained in this work. The size and turbulent nature of the Volta might have accounted for its high values. Free oxygen indicates the presence of enough primary producers in the form of phytoplanktons and periphytons and less faunal organisms in water bodies (Darchambeau et al 2013).

Table 2. Summary means of primary productivity values

Sampled Zones	Net Primary Productivity (DO (l) / mg/L)	Respiration (DO (d) / mg/L)	Gross Primary Productivity (GPP/ mg/L/hr)	FREE OXYGEN (mg/l)
Upper Portion	4.24±0.03	3.79±0.21	8.86±0.19	0.44±0.01
Middle Portion	5.20±0.05	4.23±0.06	7.50±0.42	0.67±0.07
Lower Portion	4.43±0.18	4.33±0.32	18.74±0.16	0.08±0.11
Mean Concen-Trations.	4.62±0.01	4.12±0.01	11.70±0.33	0.40±0.03
WHO Limit/ Range	6.5-8.0	0 - 6.13	10-30mg/L	4 – 15

* DO(l) indicate DO in light bottles and DO(d) indicate DO in dark bottles

Awotwe et al (2018) had indicated earlier that the concentration of dissolved oxygen in lake Bosomtwe depended on surface agitation of the water body due to temperature, rate of respiration of living organisms and the decomposition rate of dead organic matter in the water. Thus, where faunal living organisms and pollutants are few, dissolved oxygen tend to be high. Also, fishes and other aquatic organisms are mostly found at the littoral zones of water bodies leading to a higher demand of dissolved oxygen in that portion of lakes.

Net and gross primary productivities

The net primary productivity (NPP) recorded the highest value of 5.20±0.05mg/L/hr at the middle portion and the lowest at the upper part of the lake. The mean values of NPP in the lake were below that of the WHO range (UN 2014) (Table 2), and the lowest value recorded at the upper portion was due to the presence of fewer plants in the water level at the littoral portions of the lake (Fig 2B). In light, both photosynthesis and respiration occur so the measure of dissolved oxygen indicate the difference between the oxygen produced and that used by respiration in the water for a 24 hour period. The low levels of the net primary production and free oxygen indicate an inadequate presence of oxygen in the lake and poses danger to the resilience of the lake.

The gross primary productivity (GPP) was however, higher at the lower portion of the lake (18.74±0.16mg/L/hr) and a lower value of 7.50±0.42mg/L/hr at the middle portion. These were within the WHO acceptable range of 10-30mg/L (WHO 2014). The growth and spread of new plants within the water level at the lower portion of the lake as compared to the upper portion of the lake (Fig 2A&B) resulted in the high value for the GPP at the lower portion of the lake. The trend in values exhibited by the GPP was similar to that of the chlorophyll ‘a’ concentration through correlation analysis (Table 3). The difference in GPP values at the three studied portions of the lake was however, not significant (p=0.28) and the mean GPP value of 11.70±0.33mg/L/hr indicated lower presence of oxygen producing organisms in the water body.

Table 3. Correlation between primary productivity, chlorophyll a, nitrogen, chlorine, phosphorous and free oxygen

	P. productivity	Chlorophyll 'a'	N+	Cl-	P+	Free O2
Primary Productivity	1					
Chlorophyll 'a'	0.72*	1				
N^+	0.33	0.89*	1			
Cl^-	-0.15	-0.79*	-0.98*	1		
P^+	-0.87*	-0.97*	-0.76*	0.62*	1	
Free Oxygen	0.15	-0.79*	-0.98*	0.54	-0.41	1

A GPP range of 7.50-18.74mg/L for Owabi lake is within that recorded for most tropical lakes (0.8-30.90mg/L) (Horne and Goldman 1994). However, a study on Lake Mekong Basin in China showed a higher range of 40-302mg/cm^3 (Hiroki et al 2020). Lake Mekong Basin is shallow, have a larger surface area and also fed by nutrient-rich river. Beadle (1981) had indicated earlier that high productivity occurs in shallow, nutrient rich and high radiated ecosystem, and the Mekong River Basin is endowed with all these as against the Owabi lake that is relatively narrower with less nutrient inflow.

CONCLUSION AND RECOMMENDATIONS

The physico-chemical parameters studied showed lower values that were within the WHO acceptable limits/ranges, except light intensity that was below the WHO value at the upper portion of the lake as a result of the tree canopy shades. Within the nutrients, PO_4^{3-} was lower than the WHO while the NO_2^--N_2 was found to be very high and above the WHO given limit. The chlorophyll 'a' concentration was very high in all parts of the lake. The gross primary production was within the WHO limit while the net primary production and the free oxygen levels were low and inadequate. The high chlorophyll 'a' concentration in the lake, coupled with the inadequate levels of the NPP and free oxygen render the Owabi lake eutrophied, not resilient and unsustainable for aquatic organisms.

It is recommended that canopied trees that dominate the edges of the upper portion of the Owabi lake be removed to enable adequate sun energy reach the water body. Agricultural activities along the feeding rivers should be controlled to prevent leaching of agrochemicals into the rivers. The pouring of human and industrial wastes into the feeding rivers from the urban towns that surround the Owabi wetland must be monitored by appropriate agencies to prevent them being carried into the lake by the rivers to promote algae growth.

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