



Assessment of cage fish farm impacts on physico-chemical parameters of the Volta Lake in Ghana

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ABSTRACT

Although fish farming provides numerous benefits in the areas of employment, food security, nutrition, trade, and foreign exchange, among others, intensive cage culture operations could cause environmental pollution. The influence of cage culture operations on the water quality of Lake Volta in Ghana was assessed in this study. Fifteen water samples were taken every two months from April 2013 to March 2015 within the cage farm and one reference site 460 m upstream of the farm located in the Asuogyaman district. The physical and chemical parameters were measured following analytical procedures described in the standard methods for the examination of water and wastewater by the American Public Health Association (APHA). A noticeable decrease in oxygen and temperature was observed with increasing depth, typical of tropical water bodies. No major variances in concentrations of nitrate, nitrite, ammonia, phosphate (dissolved nutrients), chlorophyll-a, dissolved oxygen, secchi depths, and total suspended solids between the cage site and the reference site were detected. These results indicated that there was no considerable cage farm impact on the water quality perhaps due to the water currents of 0.061 ms^{-1} which was capable of dispersing feed from the cage farm. Consumption of stray feeds by wild fishes that gathered in the vicinity of the cage also contributed to the reduction of the impact. In addition, uptake of inorganic nutrients by phytoplankton, biological and physical interactions could account for the low impact. The lake's water quality has not yet been impacted negatively by the cage culture. The water quality should be monitored periodically for sustainable aquaculture development.

Keywords: Cage culture, Physico-chemical parameters, Water quality, Volta Lake, Fish farming

Introduction

Aquaculture is becoming central to meeting the fish demand of the world as the world's wild fish stock is being overexploited. This demand is expected to rise as the population of the world increases coupled with progressions in income and urbanization (Msangi & Batka, 2015). Aquaculture constitutes a significant source of nutrients for the underprivileged in society and it is often regarded as an inexpensive source

of animal protein (Pradeepkiran, 2019). It is contributing significantly to the development of many nations, particularly in developing countries, in the areas of employment, food security, nutrition, trade, and foreign exchange.

Despite its numerous benefits, aquaculture activities are known to create environmental problems. Incidences of water pollution due to intensive cage culture operations have been recorded in some parts of the world including Latin America, Europe, and Southeast Asia (Bascinar et al., 2014; Kashindye et al., 2018). Large quantities of waste are generated from intensive cage fish farms since the operation

relies on artificial feeds. The uneaten feed and faeces (wastes) emanating from the farm are normally released directly into the lake (Dauda et al. 2018).

The nutrient-rich feed wastes and particulates (faeces) are dispersed in the water-by-water currents. The wastes either settle on the bottom sediment or become dispersed in the water column where the organic components become decomposed by bacteria leading to the release of ammonia and other nutrients into the lake waters (Verdegem, 2013). The amount of nutrients released from the cage into the water depends on the management practices, the amount, and the quality of the feed input (Dauda et al., 2018).

Reservoirs possess the tendency to withstand and suppress nutrient loads, however, accumulation of nutrients beyond certain limits may collapse the ecosystem of the reservoir. This phenomenon may contribute organic matter, nitrogen, phosphorus, and suspended solids to the water body leading to water quality problems, particularly eutrophication (Herbeck et al., 2013). Eutrophication results from the degradation of the water quality, thus increasing pH, depleting oxygen levels, increasing hydrogen sulphide, and ammonia contents of the water body (Herbeck et al., 2013). Eutrophication promotes the growth of phytoplankton resulting in the alteration of the phytoplankton communities with its resultant effect on the biota of the ecosystem. The degree to which cage aquaculture affects water quality depends largely on production intensity, the water volume, water exchange rate, and the geology of the area (Price et al., 2015).

Lake Volta is a versatile water body that supports a variety of uses. It is used as a source of water supply to most communities in Ghana, as a mode of transportation, for fishing, as a tourist attraction site, for hydropower generation, and for agricultural/irrigation purposes. There has recently been extensive development of cage farms in the lake with a significant increase in the number of commercial cage fish farms in the lake. The fish production output from the cage farms was noted to have increased from 2009 (4,912 tonnes) to 38,547 in 2014

(MoFAD, 2015). Cage fish farming activities in the lake alone contributed about 34,692 tonnes of fish, representing approximately 90 % of the total aquaculture production in Ghana in 2014 (MoFAD, 2015). Consequently, the lake could receive a substantial nutrient load from fish waste. However, information on cage fish farm impacts on water quality parameters of the lake is scanty although research on other aspects of the lake including production parameters and economics (Ofori et al., 2010), and cage culture practices, constraints, and opportunities (Anane-Taabeah et al., 2011) have been carried out. This study was thus aimed at assessing the potential impact of a tilapia cage fish farm on the water quality parameters of the Volta Lake in Ghana.

Material and Methods

Study area (Lake Volta)

The lake, which is depicted in Fig 1, is situated between longitude 1° 30'W and 0° 20'E and Latitude 6° 15'N and 9° 10'N and remains one of the world's largest artificial lakes with a shoreline of 4,800 km. It spans about 8,500 km² area, and has a storage capacity of 148,000 Mm³, giving a mean residence time of 3.7 years for the reservoir (Barry et al., 2005). The lake has a length of about 450 km and 19 m mean depth. It represents 3.6% of the surface area of Ghana. The lake forms part of the Volta Basin. The Volta basin has a catchment area of approximately 394,000 km², shared by 6 West African countries in different proportions including Burkina Faso (43%), Ghana (42 %), Togo (6%), Mali (3 %). The rest are 3 % in Benin, and 3 % in Ivory Coast (Barry et al., 2005).

Underlaid the Volta basin is the Voltaian formation which consists of mudstones, sandstone, and shales. Pre-Cambrian is another formation in the Volta Basin. It is classified into Tarkwaian, Birimian, and Buem rocks (Dickson & Benneh, 2004).

The study area has a tropical continental/savanna-type climate. There is only one wet season in the North which starts in May and ends in November, with the peak

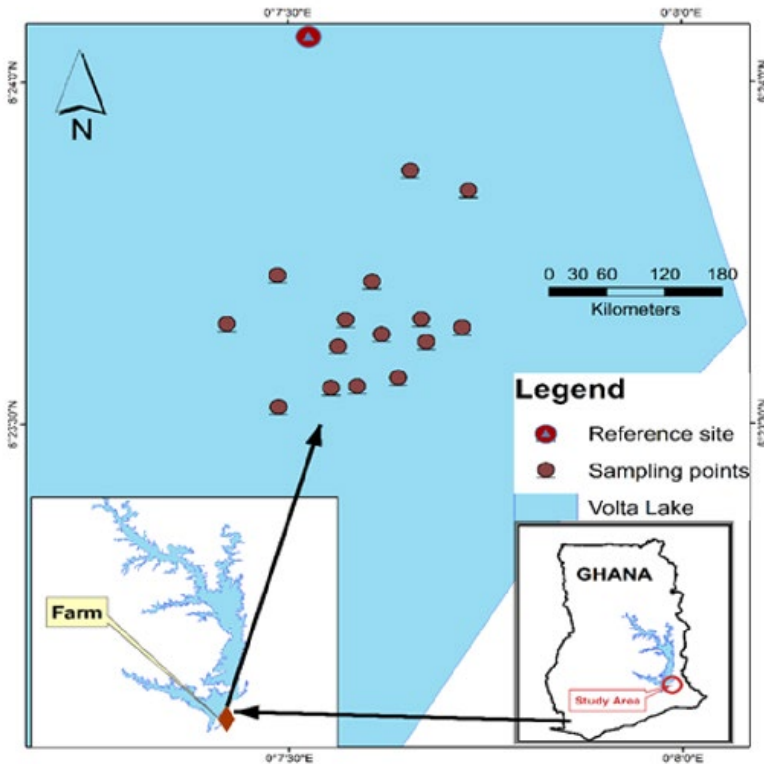


Figure 1: Map of volta lake showing the farm.

rainfall occurring in September. The south is characterized by a bimodal rainy season which occurs between June and July, and September and October. The yearly rainfall ranges between 1000- and 1150-mm while the average yearly temperatures reach 30 °C. Relative humidity ranges between 20 % in the north during the harmattan (northeasterly winds) and 90 % in coastal areas (MacCartney et al., 2012). The harmattan occurs from December to February and brings along hot, and misty conditions without rain, originating in the Sahara. Easterly winds dominate over the reservoir in June and July, bringing thunderstorms and heavy precipitation. The reservoir comes under the effect of the moist southwesterly to southeasterly monsoon by August, with extended light rain (MacCartney et al., 2012).

Crop production is the major land use activity in most parts of the basin, with the rest of the land area used for livestock grazing. The majority of the inhabitants in the basin are farmers involved in either livestock rearing or

crop cultivation or both. Drawdown farming is prevalent along the lake where sweet potatoes and vegetables are mostly cultivated during the dry season when the water level recedes (Amatekpor, 1999). Intensive cage fish farming has been carried out in the lake over the last decade (Kassam, 2014).

Study site

The study site was a cage fish farm located on Volta Lake (Fig 1) and was chosen based on the willingness of the farm owners to avail their farm for the study. The farm was one of the biggest cage farms (about 185,993.52 m²) on the lake at the time of the study and was established in 2008. It had a hatchery facility for fingerlings production located 100 m from the lake. Grow out cages were found in nearshore waters extending to about 500 m from the shore with a mean depth of 30 m. The farm had 120 cages consisting of 60 rectangular and 60 circular-shaped cages that were used for fish production. The circular

cages were 6 m deep and 16 m in diameter whilst the rectangular ones were 5 m x 5m x 6 m in size. The cages were organized in two parallel arms. Each arm was 500 m long with both sides accommodating cages. Both imported and locally manufactured extruded feeds were used in the farm and feeding was done by hand. The fish feed is composed of the following: (Crude Protein 33 - 41 %; Nitrogen 5.6 - 6.6 % ; Phosphorous 1.3 - 1.4 %; Carbon 41.9 - 42.9 % ; Moisture 8.4 - 8.7 % ; Ash 7.7 - 8.9 %). About 3,910 tonnes of fish feed was applied in 2014, stocking density was 41 fish/m³ and the average size of fish stocked was 2 g fish. About 2,300 tonnes of fish were produced in the farm in 2014 with an average FCR of 1.7.

Sampling

The water samples were taken at 15 sites within the farm, and one at the reference site 460 m upstream of the farm. No sampling was undertaken directly from the cages. The sampling sites were located between 2.5 m and 120 m from the cages. The water samples were taken once every two months from August 2013 to April 2015 at the surface (1 m below the water surface), and the bottom (1 m above the sediment) into clean 1 litre plastic bottles using a 3.0 L Van Don sampler. On each occasion, the sampling started at about 8:30 am and ended around 3:30 pm. The water samples were chilled on ice in an icebox and transported to the CSIR Water Research Laboratory, Accra, for analysis.

Water quality analyses

Temperature, conductivity, and pH were measured *in situ* using a multiparameter (Wagtech Maji-Meter, WAG-WE 51000, UK). The transparency/Secchi depth measurement was achieved by using a 20 cm diameter black-and-white Secchi disk. Dissolved Oxygen (DO) measurement was taken *in-situ* using YSI model 13J100771, version 3.3.0 meter, USA. Turbidity was determined with a HACH 2100P turbidimeter.

For chlorophyll-a analysis, the water was sampled into a clean plastic container (1 litre) and placed in an icebox. It was then transported

to the laboratory. One litre of the water was filtered through Whatman GF/C filter paper followed by chlorophyll-a extraction with 90 % acetone overnight. The extract was centrifuged at 3200 rpm for 10 minutes. Thereafter, about 4 ml of the supernatant was poured into cuvettes and the measurements were taken at 663, 645, and 630 nm, respectively using PG Instruments T60 UV-Visible spectrophotometer (Method No.10200 H, APHA, 2012). Chemical Oxygen Demand (COD) measurement was done by employing the closed tube reflux titrimetric method (Method No. 5220 C, APHA, 2012).

For analysis of NO₂-N, PO₄-P, NO₃-N, and NH₄-N (dissolved inorganic nutrients), 100 ml of water samples were filtered utilizing a filter paper (Whatman GF/C). Nitrite-nitrogen (NO₂-N) was determined by the diazotization method while nitrate-nitrogen (NO₃-N) determination was achieved through the hydrazine reduction method. Ammonium-nitrogen (NH₄-N) was determined by the direct nesslerisation method, and orthophosphate (PO₄-P) by the stannous chloride method. Total phosphate was measured using the ascorbic acid method. The nutrients were all determined calorimetrically based on the procedures outlined in Standard Methods for the Examination of Water and Wastewater (APHA, 2012).

Wild fish observation

Several different wild fish species were observed roaming around the neighborhoods of the fish cage. These wild fishes fed on the escaped feed from the cage.

Meteorological and lake water level data acquisition

The average daily wind speed and rainfall data were acquired from the Ghana meteorological station at Akuse (1° 38.532'N, 4° 33.87'E) from January 2010 to December 2015. The station is situated approximately 26 km from the lake and it is the nearest well-managed station to the fish farm. The acquired data thus represent the general meteorological settings of the fish farm. The daily water level data of the lake (in metres) were obtained from the Volta River Authority (VRA) at Akosombo

between January 2010 and April 2015.

Water current data acquisition

The water movement of the lake at different depths (1 m and 10 m) was determined using drogues. The measurement was achieved through the horizontal deployment of the drogues across the lake at approximately 50 m intervals. A GARMIN 72 H global positioning system was used to record the time and positions after every 30 minutes' interval which enabled the direction, velocity, and movement patterns of the water to be measured. Three measurements were taken in the farm from 2014 and 2015 from which the mean current velocity and direction were computed. The measurements were confirmed with a Valeport model 0012B, version 4.01 self-recording meter.

Statistical analysis

The statistical analysis was achieved with spss version 21. Analyses of the results were achieved by employing a one-way analysis of variance (ANOVA). Tukey's multiple comparisons of means were then used to assess the existence of variances in the physicochemical parameters measured in the farm and the reference site. Probabilities of $p < 0.05$ were considered significant.

Results

Meteorological data

The basin under study experiences a

bimodal rainfall pattern. The first rainy season starts from April with a peak in May/June as shown in Fig 2. The second rainy season has a peak in September/October. The rest of the year is drier from November to March and July to August.

From the data, August recorded the lowest rainfall of 0 mm in 2013; 5.1 mm in 2011, and 34.2 mm in 2010. The highest rainfall amount of 227.1 mm was recorded in June 2014 (Fig 2). The wind speed indicated moderate values with the lowest value of 0.342 m s^{-1} recorded in December 2013 and the highest value of 1.842 m s^{-1} in August 2014 (Fig 3).

Water level of the lake

From the beginning of the study, the lake level had been dropping from March 2013 (79.3 m) to April 2015 (73.7 m), as depicted in Fig 4. The lowest level of the lake, 72.7 m, was observed in June 2014. The lake begins to fill up from August–September and then started reducing from December until the lowest level in May–July. However, since February 2013, the level of the lake dropped steadily until April 2015.

Nutrients

Temporal differences in the mean monthly levels of $\text{NH}_4\text{-N}$, $\text{NO}_2\text{-N}$, $\text{PO}_4\text{-P}$, and $\text{NO}_3\text{-N}$, concentrations in the water column (both surface and bottom) of the farm are shown in Fig 5. $\text{NO}_2\text{-N}$ concentration in the farm surface water was in the range of 0.001 to 0.006 mg/L while 0.001 to 0.004 mg/L was detected in the

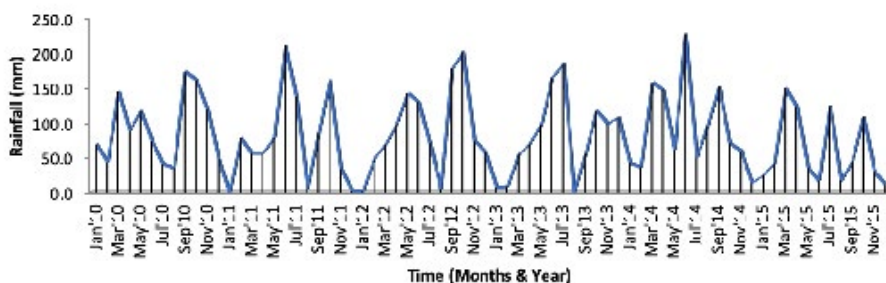


Figure 2: Monthly total rainfall (mm) observed at Akuse meteorological station

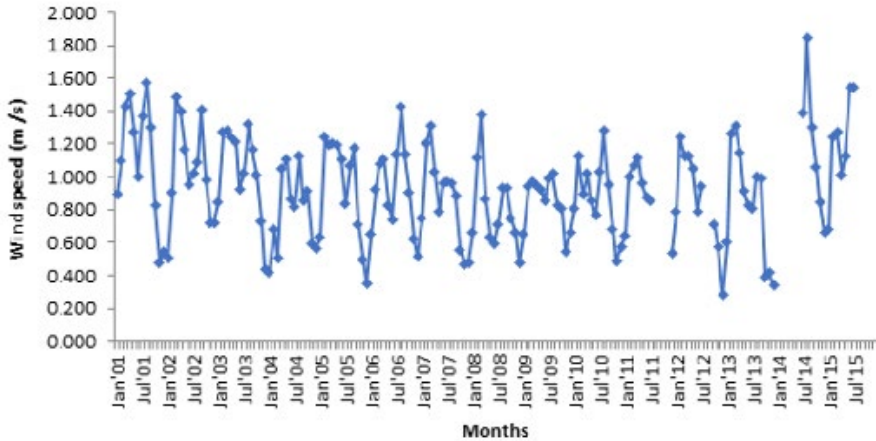


Figure 3: Daily average wind speed (ms⁻¹) observed at Akuse meteorological station.

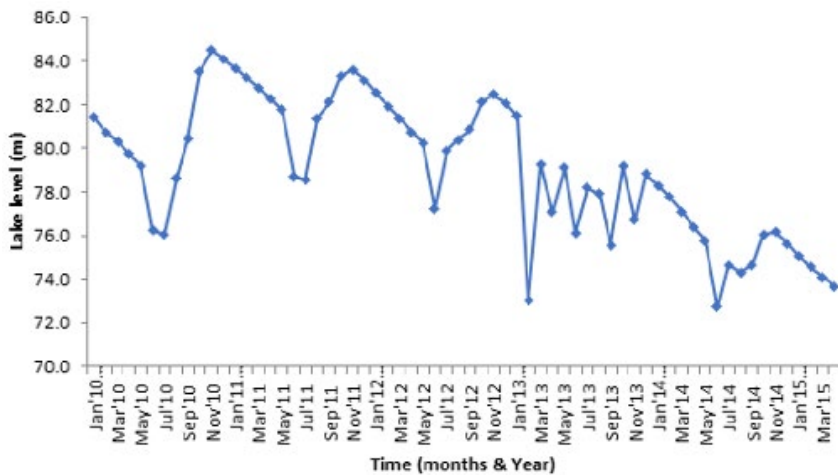


Figure 4: Lake volta level (m) fluctuation observed at the dam site.

bottom water. With regards to the reference site, nitrite (NO₂-N) concentration in the surface and the bottom waters of the farm range from 0.001 to 0.013 mg/L and 0.001 to 0.004 mg/L respectively. According to one-way ANOVA analysis, no significant differences ($p > 0.05$) were observed for the levels of NO₂-N at the reference site and the farm.

The water column NO₃-N (nitrate) concentrations ranged from 0.001 to 0.142 mg/L (surface water), and from 0.001 to 0.167 mg/L (bottom water). On the other hand, the NO₃-N levels in the surface water of the reference site varied from 0.002 to 0.202 mg/L, and that of the bottom water ranged from

0.001 and 0.202 mg/L. A similar temporal pattern of NO₃-N was recognised for the farm and the reference site (Fig 5), but the pattern was unclear. Meanwhile, no major change in NO₃-N concentration was observed for the farm and the reference site.

The farm's level of NH₄-N (ammonium-nitrogen) changed in the surface water from 0.001 to 0.269 mg/L and that of the bottom water varied from 0.001 to 0.301 mg/L. Generally, low levels of NH₄-N were detected at the initial stages of the monitoring. However, the levels increased in June 2014 and declined until February 2015. Similar concentrations of NH₄-N were recorded for both the farm and

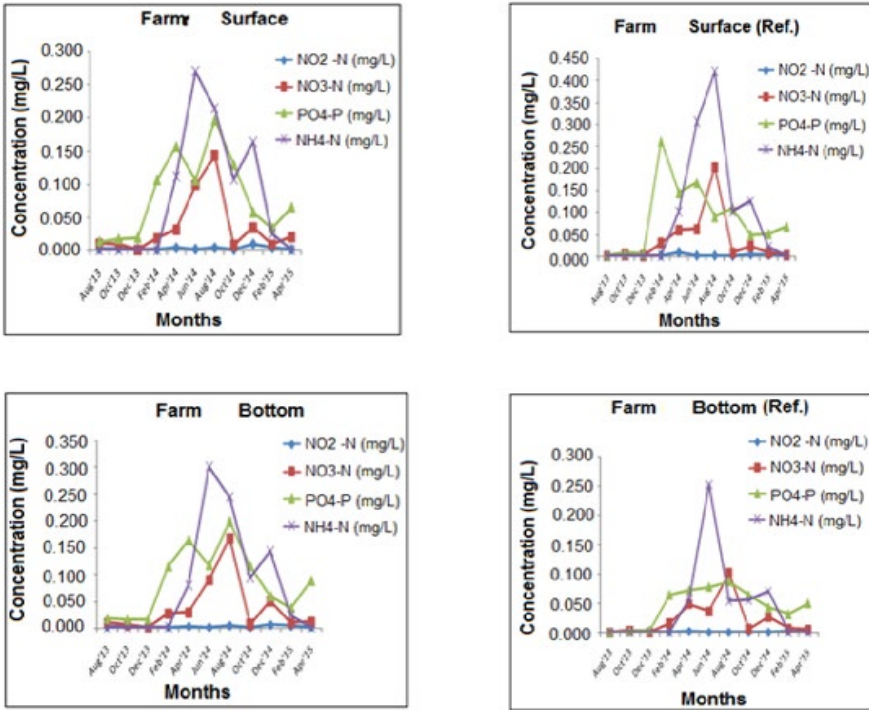


Figure 5: Temporal variation of mean dissolved nutrients ($\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, $\text{PO}_4\text{-P}$) in the farm and reference site of Lake Volta, Ghana.

the reference site. No clear change in $\text{NH}_4\text{-N}$ levels ($p > 0.05$) was detected between the reference site and the farm.

For $\text{PO}_4\text{-P}$ (Orthophosphate) concentrations in the water column, the surface water values changed from 0.013 to 0.196 mg/L while that of bottom water fluctuated from 0.016 to 0.199 mg/L. The reference site surface and bottom water $\text{PO}_4\text{-P}$ levels fluctuated from 0.001-0.261 mg/L and 0.001-0.174 mg/L respectively. No significant variation in $\text{PO}_4\text{-P}$ levels ($p > 0.05$) was detected between the farm and the reference site.

Fig 6 illustrates the variations in TP and chlorophyll-a concentrations. Values in the range of 21.6 to 311.3 $\mu\text{g/L}$ (at the farm) and 3.0 to 380 $\mu\text{g/L}$ (at the reference site) were obtained for TP. With regards to chlorophyll-a, concentrations ranging from 1.19 - 7.05 $\mu\text{g/L}$ at the farm and 1.07 - 6.18 $\mu\text{g/L}$ at the reference site were determined. No distinct relationship existed between TP and chlorophyll-a concentrations.

Transparency and turbidity

Table 1 represents the transparency and turbidity values. The results for transparency varied from 2.12 to 3.28 m on the farm. That of the reference site varied from 2.22 to 3.80 m. Transparency values in the reference site were higher than that of the farm site. A noticeable decrease in transparency was observed during the rainy season (in June) and increased during the dry season (from December – February). Surface water turbidity values ranging from

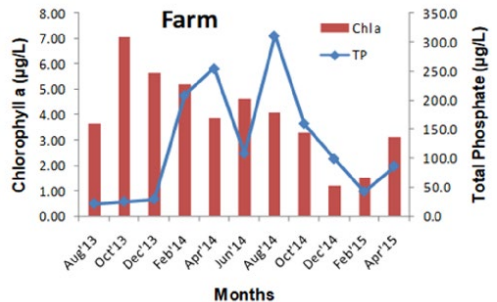


Figure 6: Mean concentrations of chlorophyll a (Chl-a) and total phosphate (TP) of surface waters in of the farm.

Table 1 - Temporal variation of transparency and turbidity in the farm and the reference site.

Sampling date	Transparency (m)		Turbidity (NTU)	
	Farm	Farm Reference	Farm	Farm Reference
August 2013	2.56	2.72	2.60	2.20
October 2013	2.34	2.49	2.33	2.10
December 2013	2.46	2.60	2.59	2.10
February 2014	2.57	2.66	1.90	1.65
April 2014	2.70	2.78	2.00	2.20
June 2014	2.43	2.63	3.43	3.29
August 2014	2.62	2.74	2.20	1.50
October 2014	2.24	2.35	1.53	2.00
December 2014	2.14	2.22	1.07	1.00
February 2015	3.28	3.80	1.00	1.00
April 2015	2.12	2.38	1.80	4.00

1.00 to 3.43 NTU were obtained in the farm while those of the reference site ranged from 1.00 - 4.00 NTU. The turbidity levels in the farm site were most of the time higher than the reference site.

Dissolved oxygen (DO) and temperature profiles

The variation in surface water average DO concentration of the farm and its reference site are illustrated in Fig 7. DO values ranging from 5.52 to 8.40 mg/L for the farm and 5.51 to 8.72 mg/L at the reference site were obtained. The DO profiles revealed that the water columns consisted of upper oxygenated water and deeper lower DO waters.

In December 2014, the DO values of the

farm varied from 8.05 mg/L at 1m through 7.35 mg/L at 5 m depth to 0.53 mg/L at 19 m depth (Fig 8). The reference site showed analogous DO conditions as the farm with 105 % oxygen saturation at 1 m depth and 1.06 mg/L at a depth of 19 m. Although comparatively lesser levels of DO were obtained at upper layers for both the farm and the reference site in February 2015 (Fig 8), the DO values were consistent until a depth of 19 m. The concentration of oxygen determined in the farm during the monitoring is considered appropriate for ecosystem use and tilapia farming.

Generally, there was a decrease in the temperature from the surface to the bottom of the water in both the farm and the reference

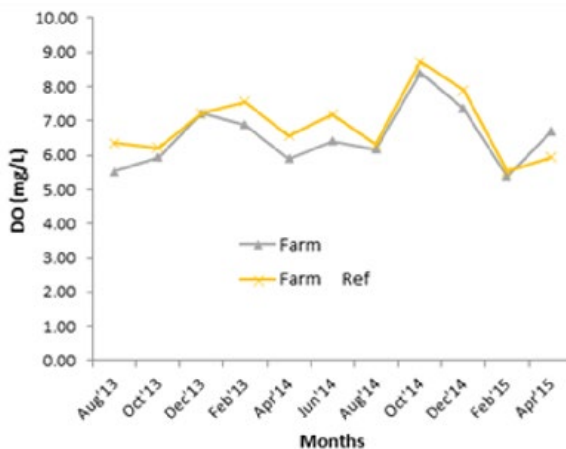


Figure 7: Temporal variation of mean do in surface waters of the farm and the reference site.

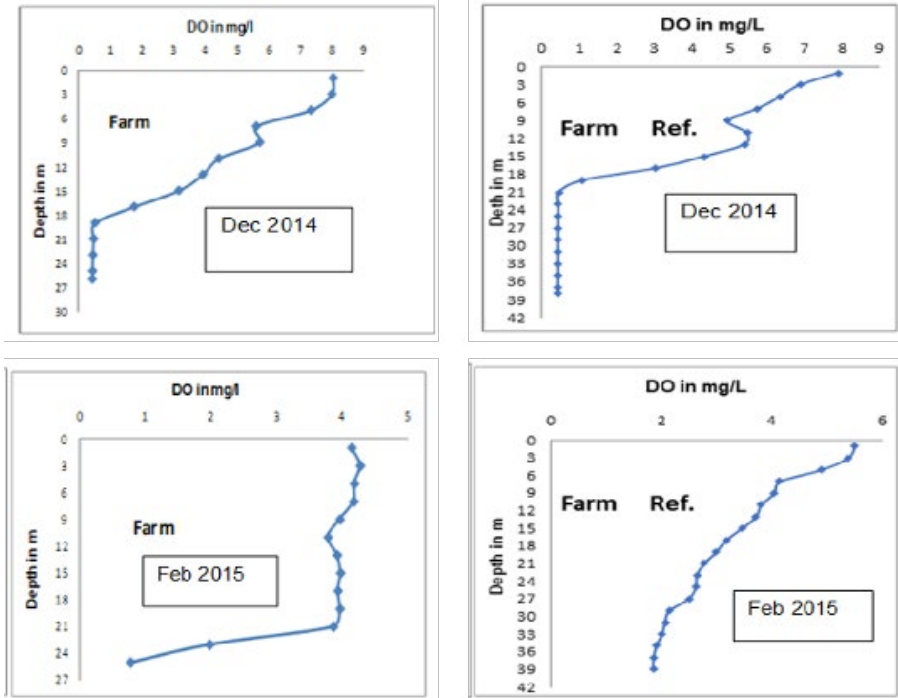


Figure 8: Dissolved oxygen (DO) profiles in the farm and the reference site.

sites. Fig 9 depicts the temperature profile. The temperature decreased from 30.1 to 29.0 at depth 9 m in December 2014 while, dropping from 27.6 °C to 27.4 °C in February 2015 at depth 9 m. At the reference site, the temperature dropped from 29.5 °C to 29.0 °C and from 27.6 °C to 27.4 °C, respectively in December 2014 and February 2015 at depth 9 m. Even at the highest depth of 38 m, the temperature change between the surface and the bottom was 2 °C.

Physical and chemical parameters

Presented in Fig 10 is the minimum and maximum, the mean, and the standard error of some of the chemical and physical parameters determined at the study area. The temperature of the surface water exhibited temporal variation and was uniform at all sampling sites. The pH of the surface water was in the range of 6.4 - 8.7. That of the reference site ranged from 6.6 and 8.6. It was observed that the pH varied uniformly. The conductivity of the surface water and the reference sites were determined to range from 55.3 to 88.7 $\mu\text{S}/\text{cm}$ and 57.5 - 83.30 $\mu\text{S}/\text{cm}$, respectively. Moderate

COD levels were determined for the surface and bottom waters at all sample sites. The mean COD for the farm surface was 15.2 ± 0.55 mg/L; that of the reference site was 14.8 ± 1.42 mg/L. The $p > 0.05$ value obtained for the chemical and physical parameters between the reference site and the farm indicates that there was no significant difference between the two parameters at the farm and the reference site.

Results of the water current data indicated average current speeds of 0.105 m s^{-1} and 0.057 m s^{-1} at 1 m from the surface and 10 m depth, respectively in August 2014. These may be considered high currents especially the 1 m surface current. Both currents were moving in the same direction. The currents were primarily to the northeast. Any distribution of waste from this area would be towards the northeast. During March 2015 deployment, current speeds of 0.111 and 0.073 m s^{-1} were measured at 1 m surface at the farm using drogue and valeport, respectively. At depth 10 m, 0.060 and 0.061 m s^{-1} were recorded by drogue and valeport, respectively. A valeport impeller current meter was used to confirm the

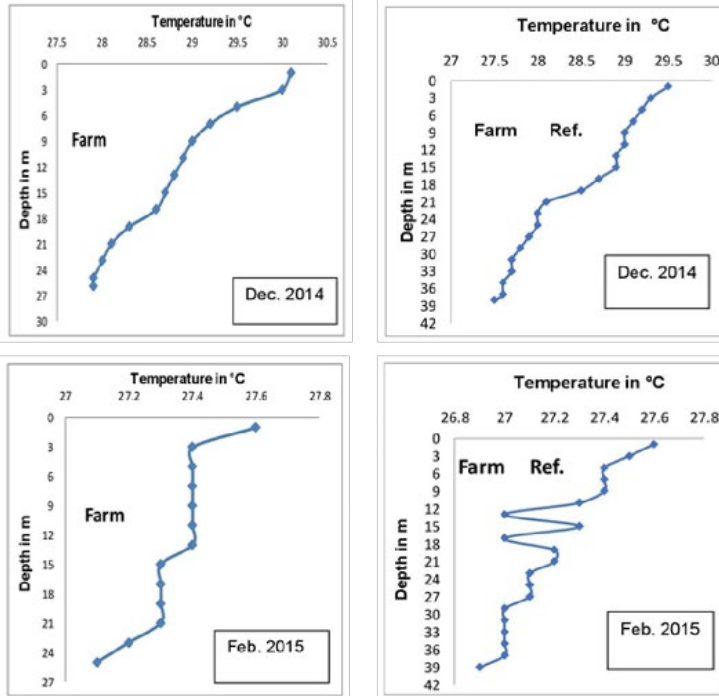


Figure 9: Temperature profiles in the farm and the reference site.

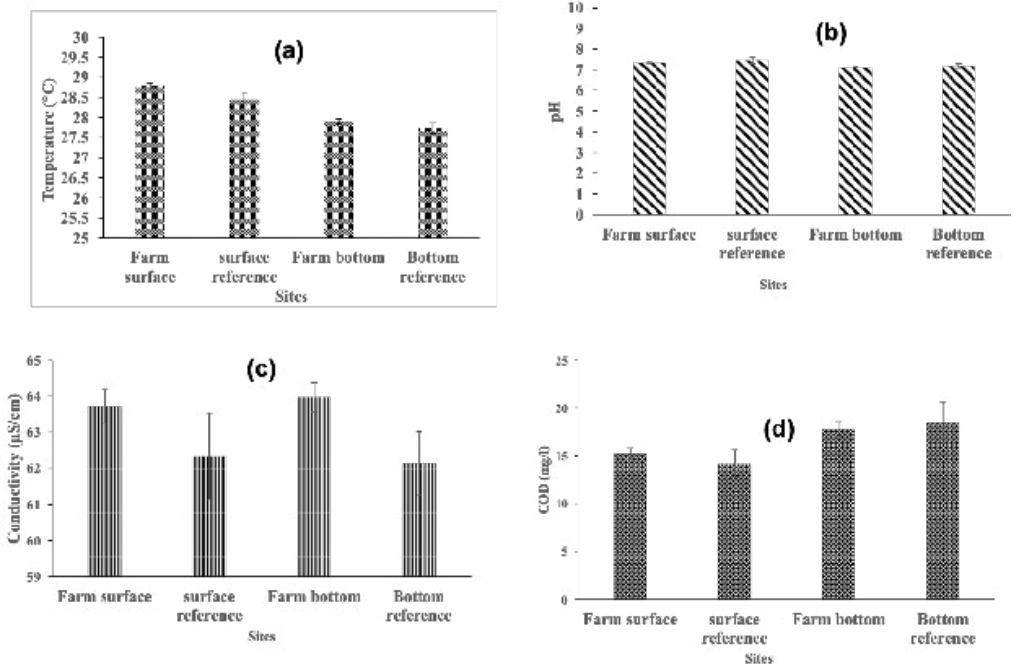


Figure 10: Mean and standard error values of (a) temperature, (b) pH, (c) conductivity, and (d) COD of the farm surface, bottom, and reference sites.

current speed.

Discussion

Water currents in the fish farm

The speed of a water current determines the level of dispersion of pollutants in that water body (Durães, 2018). As a result, the degree of dispersion of the organic wastes produced through the cage fish farming activities in the lake's environment depends largely on the water current. The faster the water current, the higher the degree of dispersion, and the farther the organic wastes are dispersed away from the fish farm (Bannister et al., 2016). This implies that farm areas with low water current have the potential to accumulate more organic wastes in the sediment, and hence will be highly impacted by the fish farming activities compared to areas with higher water current.

The mean velocity of the water current during the study period at depth 10 m was 0.062 m s^{-1} . This current was moderate and capable of dispersing nutrients from the cage farms. According to Alpaslan and Pulatsü (2008), a water current velocity of 0.04 m s^{-1} was able to effectively disperse the wastes generated by rainbow trout (*Oncorhynchus mykiss*) cage farms in a Turkish reservoir. Similarly, an average water current velocity of 0.093 m s^{-1} was observed by Gondwe et al. (2011) to have adequately dispersed the wastes discharged by tilapia cage fish farm in Lake Malawi. The lake's surface water current was noted to have been mainly driven by the wind, and the residual flows were directed north-eastwards. The quality of the water in the caged fish farm was good partly due to the water current that was capable to disperse waste away from the farm.

Temperature, dissolved oxygen, and their profiles

The water temperature at all the sampling sites reflected the weather conditions and displayed resemblances. The farm and reference site temperature profiles of the water at different depths varied between 27.6 and 30.1°C. This represents a temperature difference of 2.5 °C between the surface and the bottom waters in the farm. According

to Darko et al (2019), stratification could develop when the surface and bottom water temperature ranges between 0.2 and 3.5 °C. Hence, the result signifies the occurrence of a clear water column thermal stratification with seasonal weather variations. The 26.6 and 30.9 °C temperature range is significant enough to influence the rate of decomposition of organic wastes discharged from the cage farm (Gondwe et al., 2011). The decomposition of fish wastes and excess food has the potential of reducing DO levels near the cage site, but DO reduction depends on the water exchange rate, fish density, and feeding rates. The obtained temperature ranges in the reference site and the farm fell within the optimum temperature range of 25–32 °C proposed by Boyd (2003) for fish growth. A previous study carried out on the lake by Karikari et al. (2013) indicated a similar temperature range of 27.5 to 30.0 °C.

One of the necessary parameters for aquatic life is dissolved oxygen. DO has been used primarily as a means of indicating localized cage fish farm pollution in most water bodies. In this study, 4.58 to 9.33 mg/l was the DO concentration determined in the farm and the reference site surface waters with 61.5 and 125 % as the percentage saturation variations. The determined surface water DO values were well beyond the recommended critical farm value of 3.7 mg/l for sustainable aquaculture by Abo and Yokoyama (2007). The present DO values in the cage farm of Lake Volta were consistent with those obtained in the same lake (7.3-8.1 mg/L) by Karikari et al. (2013) and 4.35 to 7.68 mg/L in a cage farm in Lake Malawi (Gondwe et al., 2011). There was no clear temporal pattern with regards to the surface water DO. However, the pattern on the farm and the reference site were similar (Fig 7). The mean DO value of the surface water of the reference site was slightly higher than that of the farm but to a marginal extent. This comparatively low DO value of the farm could mean that there was a minor effect of the cage fish farm on the water quality. The low oxygen concentration could be due to oxygen consumption by the caged fish and wild fish population, thereby reducing concentration at the farm perimeter

(Macuiane et al., 2016). The low oxygen in the farm could also be due to the decomposition of fish wastes and excess food. The DO profile depicted in Fig 8 revealed upper oxygenated waters and deeper near anoxic waters. This pattern is commonly seen in tropical water bodies (Siriwardana et al., 2019). Bottom waters with DO values as low as 0.53 mg/l were determined although reasonable DO values of 3.17-5.41 mg/L were obtained at 13m depth.

Nutrients and other physico-chemical parameters

pH, conductivity, NO₃-N, NO₂-N, NH₄-N, and PO₄-P (nutrient), turbidity and chlorophyll-a, did not show any significant difference ($p > 0.05$) between the reference site and the farm. Consequently, there was no increase in concentrations of these parameters determined at the farm site. Gondwe et al. (2011) made a similar observation in a tilapia cage farm in Lake Malawi. Many studies (Pitta et al., 1999; La Rosa et al., 2002; Nordvarg & Johansson, 2002; Soto & Norambuena, 2004) have indicated no noticeable effect of fish farming on water column parameters at short spatial scales. Some of the reasons might be due to the presence of water currents and sufficient depths to distribute and dilute cage wastes harmful to the surrounding environment. Nutrients including nitrates, nitrite, and orthophosphate can be easily taken up by macroalgae and phytoplankton (Li et al., 2016). Fish wastes/feecal matter and uneaten feeds sink quickly to the bottom of the water and accumulate in the sediments (Ballester-Moltó et al., 2017) where they get consumed by detritus-eating organisms.

No major difference in chlorophyll-a and total phosphorus (TP) concentrations ($p > 0.05$) was established between the farm and the reference site. 7.00 µg/L was the highest value of chlorophyll-a determined in October 2015. A previous study conducted on the Volta Lake by Karikari et al in 2013 recorded 19.0 µg/L of TP. The optimum chlorophyll-a value established as the standard in the Northern European waters beyond which eutrophication can occur is 10 µg/L (Basaran et al., 2010). The subregion, for that matter Ghana, has

no established chlorophyll-a standard. Phosphorus, according to Tang et al. (2020), is noted to be a major nutrient that determines the eutrophication status of reservoirs. The highest TP concentration was recorded in February-April 2014 after which it decreased abruptly in June 2014. This decrease in TP concentration paralleled the highest rainfall value of 227.1 mm, and the lowest water level of 72.7 m in June (Fig 4). Meanwhile, a significant reduction in transparency and a rational upsurge in turbidity were noted on the farm in the same month (Table1). Because phosphorous serves as a limiting factor to phytoplankton growth, there is the possibility that the reduction in TP was a result of its uptake by phytoplankton which in turn minimized the transparency and raised the turbidity level. A contributing factor to this phenomenon may be the combination of the rains and the lowest water level. The TP varied temporally.

Our previous study (Karikari et al., 2020) also revealed that the total organic carbon (TOC), total phosphorus (TP), and total nitrogen (TN) contents of the farm sediment were in the ranges of 2.57-5.22%, 0.100-0.605% and 0.222-0.450, respectively. These results, according to Méndez (2002), indicated that the farm sediment was slightly contaminated. This point supports the observation that fish wastes/feecal matter and uneaten feeds sink quickly to the bottom of the water and accumulate in the sediments, leaving the water column relatively unpolluted.

Effects of wild fishes aggregation in the vicinity of cages

In the aquatic environment, floating structures are identified as efficient attractants of fish. While fish cage structures are identified to attract wild fish due to the presence of uneaten fish feed that escapes through the cages into the water, fouling organisms can also facilitate the attraction effect (Uglen et al., 2014). Numerous wild fish species were observed around the cage in the lake during the study period, and this observation has been made in various studies across the world. However, estimation of the number of fishes around the cage was not within the scope of

this study. Dempster et al. (2004) observed large collections (30,000–88,000) of wild fishes around four Mediterranean farms but detected a few at the reference site. A study involving a cage fish farm situated in the sea in the Canary Islands documented 15,204 wild fishes consisting of 23 fish taxa and 15 families. This number of wild fishes was about fifty folds higher than those observed at two control sites (Tuya et al., 2006). The dependence of the wild fishes on the feed waste emanating from the cage farms influences the dispersal of the waste around and below the cages as most of them are consumed and the rest are spread far away from the farm by the movement of the wild fishes (Ballester-Moltó et al., 2017). It has been observed by Uglem et al. (2014) that feeding activity of the wild fishes on the stray feed around the cage diminishes the amount of the feed that reaches the bottom and thus lessens its effects on the benthos. The consumption of feeds exiting the cages by wild fishes significantly reduces the impact of the cage farms on the water quality.

Conclusion

The results of the study revealed a marked decline in temperature and oxygen profile with increasing depth. No substantial variations in the concentration of nitrate, nitrite, ammonia, phosphate (dissolved nutrients), chlorophyll-a, total suspended solids, Secchi depths, and dissolved oxygen were noted between the cage farm and the reference site. The cage culture activity did not exert any significant impact on the water quality of the cage environment of the Volta Lake. The nominal influence of the cage fish farm on water quality can be assigned to the dispersion of feed waste by the water currents, the probable feeding of waste by schools of wild fishes that assembled around the cages particularly during feeding of the fishes, and nutrient reduction through dilution. As the cage fish farming activities on the lake expand, a corresponding increase in waste generation is likely to occur leading to potential pollution of the lake's environment. The design of a long-term programme for continuous monitoring of the quality of the

lake in order to attain sustainable development of cage culture in Lake Volta should, therefore, be a paramount interest of the stakeholders.

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Author contributions

All the authors listed have made significant contributions at the various stages of the preparation of this manuscript and hold themselves responsible for the content of the manuscript.

Compliance with Ethical Standards

Authors declare no conflict of interest in the publication of this article and have agreed on its publication in this journal. The research did not involve human participants and/or animals and hence did not require any informed consent.

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