

Heavy Metal Concentrations and Sediment Quality of a Cage Farm on Lake Volta, Ghana

Karikari, Anthony Yaw. ^{*1}, Asmah, Ruby.¹, Anku, William Wilson.¹, Amisah, Steve.², Agbo, Nelson Wheatson. ², Telfer, C. Trevor.³, Ross, Glenn Lindsay.³

¹CSIR Water Research Institute, Accra, Ghana

²Kwame Nkrumah University of Science & Technology, Kumasi, Ghana

³Institute of Aquaculture, University of Stirling, United Kingdom

*Corresponding author: E-mail: aykarikari@hotmail.com; Tel: 233208184215

Abstract

This study involved the determination of sediment quality and heavy metals in the water column and bottom sediment of a selected cage fish farm in Lake Volta, to assess the potential impact of metals and organic matter pollution on the lake due to cage fish farming. Sediment analysis indicated that the texture of all sampling sites was sandy clay loam with sand dominating with a range of 31.5 – 81.2%. The Organic matter (TOM) ranged from 4.42 – 8.89%, while organic carbon (TOC) was from 2.57 – 5.22%. Total nitrogen (TN) fluctuated between 0.22 and 0.45%; total phosphate ranged between 0.22 and 5.30%. The TOC, TOM, and TN content in the farm sediment were significantly lower than those of the reference sites (ANOVA, $p < 0.05$). Lead, copper, cadmium, and selenium were not detected in the water. The results revealed that heavy metals concentrations in the water column and sediments were low and within tolerable levels, indicating no influence of metals from fish feed was observed on the lake water quality. However, the farm seemed to have moderate impact on sediment quality from organic matter. Water and sediment quality monitoring should be embarked upon periodically to ensure sustainable cage culture in the Lake Volta.

Keyword: Lake Volta, heavy metals, cage fish farming, organic matter, lake sediment.

1. Introduction

The environmental impact of aquaculture wastes is a major global concern as it has a potentially detrimental effect on the aquatic environment with nutrients, heavy metals, organic matter, and other waste outputs. Although metals exist naturally in rocks in the aquatic environment and hence enter aquatic ecosystems through weathering of rocks, anthropogenic contributions from agricultural activities, including fish farming, is believed to be introducing more heavy metals

into the aquatic environment (Chen *et al.*, 1999). Metals such as magnesium (Mg), zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), selenium (Se) arsenic (As) and cobalt (Co) are incorporated into fish feed to fulfill mineral requirements (Elnabris *et al.*, 2013). Fish faeces and uneaten feed contain high amounts of phosphorus, nitrogen, carbon and heavy metals compared to the natural sediment (Morrisey *et al.*, 2000). Hence, sediments underneath cage fish farms are predisposed to further pollution by heavy metals and other fish meal constituents from fish faeces, antifouling chemicals applied for the protection of cage nets from fouling, and uneaten feed (Basaran *et al.*, 2010).

Cage culture creation in lakes leads to the buildup of organic matter in the bottom sediment with the resultant depletion of oxygen and alteration of benthic communities. Introduction of a high quantity of waste in the sediment underneath the cages has the potential of causing anaerobic conditions (Chen *et al.*, 2000) which can potentially alter the quality of the sediment as well as the benthic community (Chen *et al.*, 2000).

Metals-fortified fish feeds are known to be contributing factors to heavy metals contamination of sediments beneath fish cages (Sapkota *et al.*, 2008). For example, elevated levels of metals including Cu, Ni, Fe, Pb, Zn, and Cd were detected in sediments and water columns under cage farms in the eastern Mediterranean (Belias *et al.*, 2003; Basaran *et al.*, 2010). Additional works by Mendiguchia *et al.*, 2006 and Sutherland *et al.*, 2007 have also detected elevated amounts of metals in lake sediments due to aquaculture activities. The human health dangers related to heavy metals pollution are many with some including toxicity to the nerves and cancer-causing effects (Sapkota *et al.*, 2008).

The Volta Lake represents a major source of freshwater fish in Ghana through cage fish farming; and although it is still considered to be on a small scale, cage fish farming in Ghana has been growing swiftly since the mid-2000s with particular emphasis on tilapia production (Kassam, 2014). Lake Volta cage fish farming contributed about 90 % (34,692 t) of the total aquaculture production in 2014; and again about 90 % (76,845t) in 2015 (Asiedu *et al.*, 2017). Intensified cage fish farming activities are posing a relatively new burden on the lake's ecosystem which may consequently accumulate substantial pollutants from fish wastes i.e. fish faeces and uneaten feed. However, there exist insufficient information on the impacts of cage aquaculture on Volta Lake. Some works have been done by researchers on specific aspects of the lake which are unrelated to cages. These include studies on the environmental impacts of

Akosombo dam (Fobil & Attuquayefio, 2003; Akrasi, 2005; Agodzo, 2013) the biological and fishery aspects of the Lake (Amakye, 2001; Ofori-Danson, 2002; Béné, 2007; Akongyuur *et al.*, 2012) and water quality (Ofori-Danson & Ntow, 2005; Gordon & Ansa-Asare, 2012; Karikari, Akpabey, & Abban, 2013; Olalekan *et al.*, 2015). Few studies have also been undertaken on the impact of cage culture on water quality of the lake (Ofori *et al.*, 2010; Mensah & Attipoe, 2013; Asmah *et al.*, 2014). However, these studies have been limited to water quality in the vicinity of the cages. Sediment qualities underlying the cages and the heavy metals content discharge from the cages into the environment have not received any attention.

This research work was therefore aimed at filling these gaps by determining heavy metals concentration in the underlying sediment and water column, and the sediment characteristics of a cage fish farm in Lake Volta, and comparing the results to a reference station farther away from the farms in order to evaluate the influence that cage aquaculture has exerted on the lake.

2. Material and Methods

2.1 The Study Area (Lake Volta)

The lake lies between longitude 1° 30'W and 0° 20'E, and latitude 6° 15'N and 9° 10'N (**Figure 1**). At the highest level, it has a surface area and a volume of approximately 8,500 km² and 149 km³ respectively, with 400 km length. It has a mean depth of 19 m and represents about 3.6% of Ghana's surface area (Moxon, 1984).

The Volta basin's catchment area is about 394,000 km² which is shared by 6 neighboring countries including Ghana, Burkina Faso, Mali, Ivory Coast, Benin, and Togo. The basin system represents approximately 70% of Ghana's total land area and occupies around 42 % of the entire basin area in the country. Daka, Oti, Afram, Pru, White Volta, Dayi, Asukawkaw and Black Volta are the rivers that drain the Volta basin system (Moxon, 1984).

The climatic condition of the basin is savanna type/ tropical continental. There is only one wet season in the North which begins from May and ends in November with September being the peak rainfall season. Two main rainy seasons, which peak from June to July and September to October, exist in the South. The yearly rainfall varies between 1000 mm and 1150 mm while the average yearly temperature around 30 °C. During the harmattan i.e. northeasterly winds, humidity ranges between 90 % and below 20% in the Coastal and Northern areas, respectively (McCartney *et al.*, 2012). The foremost land use activity in the basin is agriculture with

extensive livestock grazing activities in the rainy areas. Thus, the majority of the basin's populations are engaged in crop cultivation and livestock rearing. During the last decade, extensive cage fish farming had been undertaken in the lake (Kassam, 2014).

<Figure 1>

2.1.1 Description of the fish farm

There is a land-based hatchery facility at the farm for the production of fingerlings and is located at about 100 m from the lake. Lake-based grow out cages are also installed in nearshore waters that extend to about 500 m from the shore with an average depth of 30 m and current speed of 0.062 ms^{-1} . The fish farm uses 60 circular and 60 rectangular-shaped cages for fish production. The circular cages were 16 m in diameter and 6 m deep whilst the rectangular cages were 5 m x 5m x 6 m. The cages were organized in two arms in a V-shape, with each arm being about 500 m long with cages on both sides (**Figure 2**). Hand-feeding is employed using imported and locally manufactured extruded feeds. The total feed applied in 2014 was 3,910 tonnes and about 41 fish/m³ stocking density with 2 g fish. The annual production of the farm for the year 2014 was 2,300 tonnes with an FCR of 1.7.

<Figure 2>

2.2 Sampling

The sampling stations included a reference site located at 460 m upstream and 15 sampling sites within the farm. **Figure 3** shows the sampling sites.

The reference site was essential as it served as a pre-impact condition in circumstances where there was no environmental impact assessment (EIA) study preceding the creation of the farm. As a result, any statistically significant change observed in concentrations between the farm and the reference site could be assigned to the operation of the cage fish farm.

Collection of water samples was done once every two months using a 3L Van Don sampler into clean 1L plastic bottles. The sampling was performed 1 m below the water surface and 1 m above the sediment. Sampling of the sediment was also accomplished once every two months using an Ekman grab. They were kept in plastic bags, cooled on ice and transported to the CSIR Water Research Institute Laboratory for analysis. Sixteen (16) sediment samples were collected from the farm including a reference site located upstream of the farm.

<Figure 3>

2.3 Measurement of Water and Sediment Quality Variables

Measurement of pH, conductivity, and temperature was accomplished *in situ* through the use of multiparametric water probe/meter (Wagtech Maji-Meter, WAG-WE 51000, UK). Dissolved Oxygen (DO) measurement was taken *in-situ* through the use of a YSI model 13J100771, version 3.3.0 meter, USA. Turbidity was measured in the laboratory with a HACH 2100P turbidimeter using distilled water as a blank.

2.4 Samples Analysis

2.4.1 Determination of Total Organic Carbon (TOC) and Total Organic Matter (TOM) in Sediment

Measurement of the TOC content in the sediments was achieved based on the Walkley-Black procedure. A total of 0.1g fine sediment was weighed using an analytical scale into 500 ml wide-mouth Erlenmeyer flask. A $K_2Cr_2O_7$ solution (10 ml, 0.167 M) was added prior to the addition of 20 ml H_2SO_4 (96 %). The mixture was swirled gently to mix. Deionized water (200 ml) and H_2SO_4 (10 ml, 85 %) was added and the mixture was permitted to cool. Ferroin indicator solution (1 ml) was added and the mixture was titrated with 0.5 M solution of Fe_2SO_4 while being stirred until a sharp green colour change was noticed at the endpoint. Reagent blank (deionized water) was run using the above procedure without sediment to standardize the ferrous solution after which the carbon content of the sediment was determined. The total organic matter was calculated as % organic matter = 1.7 x % organic carbon (Allison, 1965).

2.4.2 Determination of Sediment Kjeldahl Nitrogen

A total of 1g fine sediment was digested with a sulphuric acid-selenium digestion mixture (2.5 ml) in a digestion tube. Approximately 3ml of 30 % H_2O_2 was added and the mixture was heated at 200 °C for 1h. The temperature was later increased to 330 °C with continuous heating for additional 2 h until a transparent mixture was obtained. The mixture was allowed to cool to room temperature and whirled for a while after the addition of 10 ml deionized water. An H_3BO_3 (boric acid) indicator solution (20 ml) was poured into a beaker (250 ml) and positioned underneath the tip of a condenser. A NaOH solution (20 ml, 38 %) was added to the digestion tube and 7 minutes of distillation was performed during which about 75 ml distillate was attained. The distillate was then titrated against an HCl solution (0.01M) until a pink colour

change was detected at the endpoint. The percentage of nitrogen was then calculated using the titer value (Amin & Flowers, 2004).

2.4.3 Sediment Total Phosphate

The sediment samples were oven-dried and 0.3g of the dried sample was digested using HNO₃ (8ml, 65%) and HF (2ml, 40%) mixture in a 'milestone' Ethos microwave digester (START D) at 180° C for 45 min. The solution was diluted to the 50 ml mark and left overnight to promote precipitation of suspended solids. Then, the digested sample (0.5 ml) was pipetted into a 50 ml flask followed by its dilution to 25 ml. The phosphate determination was performed at 880 nm using T 60 UV-Visible spectrophotometer following molybdate complex formation and reduction with H₃BO₃ (APHA, AWWA, WEF, 2012).

2.4.4 Particle Size Analysis- Sieve Method

Empty laboratory test sieves of 200 mm diameter with the following mesh sizes in the order: 5.0, 2.5, 1.25, 0.63, 0.50, 0.315, 0.20, 0.16, 0.071, and 0.050 mm were weighed and positioned on a shaker. Pre-weighed sediment samples were poured into the 5 mm sieve, covered and the shaker turn on for 5 min. The sediment weight remaining in each sieve was attained by finding the differences between the weights of the sieves containing the sediments and the empty sieves. In order to determine the percentage sediment retained on each sieve, the weight of the sediments retain on the sieves were divided by original weights of the sediments. Categorization of the sediment types was done using the United States Department of Agriculture (USDA) textural soil chart.

2.4.5 Oxidation Reduction Potential (ORP) Determination

Grab sediment was collected into a polyethylene bag, and the redox potential measured *in situ* by using a Wagtech Maji-meter ORP probe. The Wagtech Maji-Cal solution was used to accomplish the calibration.

2.4.6 Determination of Metals concentration in Water Column

The sampled water (100 ml) was filtered with 0.45 µm pore size filter papers. 68 % HNO₃ was added to the samples until the pH was less than 2. The water samples were then analyzed for the following dissolved heavy metals which are usually added to fish feed: Cu, Fe, Mn, Zn, Cd, Pb, and Se. Selenium (Se) was analyzed using AAS-GTA 120 graphite furnace while all the

other metals were analyzed using Agilent 240 FS Atomic Absorption Spectrophotometer (AAS-flame) with deionized water as blank (APHA, AWWA, WEF, 2012).

2.4.7 Determination of Metals concentration in Sediment

About 25 g of the wet sediment sample was oven-dried at 110°C for 4 h and weighed again after cooling in a desiccator. The drying and cooling procedure was repeated until a consistent weight was achieved. The resultant sediment was ground and sieved with a 200 mm sieve. The sieved sediment sample (0.2 g) was digested with HNO₃ (8ml, 65%) and HF (2 ml, 40%) mixture in a 'milestone' Ethos microwave digester (START D) at 180° C for 45 min (Kingston, & Walter, 1995). The final solution was diluted to 50 ml after which the suspended particles were allowed to precipitate overnight before the analysis was performed with AAS.

2.5 Quality assurance and quality control

All the instruments were calibrated before use. Blanks and quality control samples analyses were performed together with the samples for quality assurance purposes. Sediment standard reference materials (IAEA-356) was analyzed alongside sediment samples. The analyses were done in triplicates and the mean values recorded

2.6 Statistical Analysis

SPSS version 21 was used for the statistical analysis. All the results were analyzed using a one-way analysis of variance (ANOVA) followed by Tukey's multiple comparisons of means to determine if any major differences occurred between the different physico-chemical parameters checked in the farm and the reference site. Probabilities of $p < 0.05$ were considered significant. Relationships between TOC and TOM were estimated by Pearson's correlation coefficients.

2.7 Ethics statement

This article does not contain any studies involving human or animal participants, hence it does not need an ethical approval.

3. RESULTS

3.1 Water Quality Parameters

The mean, standard deviation, minimum and maximum values of the water quality parameters at the study area are presented in **Tables 1**. Surface water temperatures were found to be uniform at all sampling sites and exhibited temporal variations. The pH values of the surface water ranged from 6.4 to 8.7 and those of the reference site varied between 6.6 and 8.8. For the bottom water, the pH values were in the range of 4.2 to 8.5 while the range of the reference bottom water was 6.6-8.5. The surface water conductivity values recorded varied from 57.5-72.7 $\mu\text{S}/\text{cm}$ and that of the reference was 57.7-73.8 $\mu\text{S}/\text{cm}$ with a mean of 62.3 ± 4.8 . Conductivity values for the bottom water and reference sites were 57.5-79.8 and 58.5-71.2, respectively. DO concentration in the surface water of the farm varied between 5.4-8.4 mg/L and that of the reference site ranged from 5.5-8.7 mg/L. The bottom water DO values were 0.9-4.6 mg/L for the farm with a mean of 3.0 ± 1.3 and 0.8-4.4 for the reference with a mean of 2.7 ± 1.4 . The DO profiles were characterized by upper oxygenated water and deeper lower DO waters. Turbidity values at Farm varied from 0.5 to 3.4 NTU at the surface, 0.6 to 5.7 NTU at the bottom.

<Table 1>

3.2 Sediment Particle Size and ORP

The sediment samples obtained from all the sites were categorized as sandy clay loam with sand being the predominant texture. Sand values ranged from 32.0 to 75.3 %; and 47.9 to 81.2 % at the reference site. The silt varied from 10.7 to 31.2 while 26.0 ± 4.57 % was measured as the highest clay content (**Table 2**). A major difference ($p < 0.05$) was observed for sand, silt, and clay between the farm and the reference site, although sediment oxidation-reduction potential (ORP) and gravel did not exhibit any significant difference. ORP values ranged from 14.2 to 200 mV (**Table 4**). The sediment's pH varied between 3.93 to 7.23 at the farm and 4.35 to 6.39 at the reference site (**Table 4**). The differences in particle sizes of the sediments in the farm and the reference site of the lake are also presented in **Figure 4**.

<Table 2>

<Figure 4>

3.3 Metal Concentrations in the Water Column

The water column's (both the surface and the bottom waters) metals concentrations are presented in **Table 3**. Some of the metals including Cd, Cu, Se, and Pb were nondetectable in the water column. However, Mn, Zn, and Fe mean concentrations detected in the water column of the farm and the reference site were within the USEPA (1986) acceptable limit. The order

of the metal concentrations detected in the water column was as follows: Fe > Mn > Zn > Cu = Pb = Se = Cd. No significant difference was observed between the farm and the reference site as far as the metals' concentrations are a concern. Nevertheless, a correlation existed between Zn and Mn ($r=0.0315$, $p < 0.01$), Fe and Mn ($r=0.509$, $p < 0.01$) and Fe and Zn ($r=0.664$, $p < 0.01$), in the farm.

<Table 3>

3.4 Metal Concentrations in Sediments

Table 4 contains the results of the metals concentrations determined in the sediment samples of both the sampling and the reference sites. Contrary to the result of the water column, a considerable number of metals with appreciable concentrations, with the exception of Cd, were determined in the farm and its reference site. Iron (Fe), was the metal with the highest detectable concentration in both the farm (mean of 38,659 mg/kg) and the reference site (37,917 mg/kg). The degree to which the metals occur in the bottom sediment is presented in the following order: Fe > Mn > Zn > Cu > Pb > Se > Cd. Overall, the metals concentrations determined (in the sediments) were lower than the threshold effect concentration (MacDonald *et al.*, 2000). Substantial differences existed in the concentrations of Cu, Pb, Mn, and Zn between the farm and the reference site.

<Table 4>

3.5 Total Organic Carbon (TOC), Total Organic Matter (TOM), Total Nitrogen (TN) and Total Phosphate (TP) in Sediments

The mean TOC and TOM, TN and TP variations are illustrated in **Figure 5** and the relationship between TOC and TOM, TN and TP have been shown by Pearson's correlation coefficients in **Table 5**. The TOC values ranged from 2.57 to 5.22 % at the farm and from 3.90 to 7.00 % for the reference site. Significant differences were detected in TOC between the farm and the reference sites (ANOVA, $p < 0.05$, **Table 5**). TOM values fluctuated from 4.42 to 8.98 % at the farm and from 6.70 to 12.03 % at the reference site. The variations of TOM were similar to those observed in the TOC. Correlation between heavy metals and TOC was also analyzed but there was no meaningful correlation. The highest monthly average level was observed at reference sites in December 2013. TOM concentrations were significantly different from those at the reference site (ANOVA, $p < 0.05$).

TN values varied from 0.222 to 0.450 % and from 0.335 to 0.605 % at the farm and the reference site, respectively (**Figure 5**). TN showed significant differences between the sampling sites (ANOVA, $p < 0.05$). TP could not be measured on the sediment samples during the first year of the study. However, TP determinations were performed on the sediments from June 2014 to April 2015. The TP levels ranged from 0.100 to 0.605 % and from 0.024 to 0.325 % at the reference site. There was no significant difference between the sampling sites for TP.

<Figure 5>

<Table 5>

4. DISCUSSION

4.1 Water Quality Parameters

Water temperatures reflected the conditions of the weather and exhibited similarities at all the sampling sites. The temperature ranges observed for the farm and the reference site were well within the optimum range for fish growth of 25–32 °C (Boyd, 2007). Earlier work on the lake reported a similar temperature range of 27.5 to 30.0 °C (Karikari *et al.*, 2013). The pH and conductivity variations were observed to be uniform.

Dissolved oxygen is a very important parameter for aquatic life. In many water bodies, DO has been used as the primary indication of localized pollution of cage culture operations. The concentrations of DO found in the surface water in this study were above the “critical” farm value of 3.7 mg/l recommended by Abo and Yokoyama (2007) for sustainable aquaculture. The DO ranges in the present study were consistent with earlier oxygen values (7.3–8.1 mg/L) in the Lake Volta reported by Karikari *et al.*, (2013) and DO levels of 4.35 to 7.68 mg/L observed in a cage farm in Lake Malawi (Gondwe *et al.*, 2011). The mean surface DO concentration of the reference site was marginally higher than that of the farm. This slightly lower DO level in the farm may suggest little effect from the cage farming activity.

There was no significant difference in the turbidity values between the farm and the reference site. This suggests that increased turbidity values were not detected at the cage site. A similar observation was made by Gondwe *et al.*, (2011) in a tilapia cage farm in Lake Malawi.

4.2 Sediment Quality

The particle size analysis showed that the texture of the sediment was sandy clay loam at all the sampling sites (**Figure 3**). The sand content in the sediments analyzed had a range of 31.5 – 81.2 %. The larger the diameter of sediment particles, the higher the ability of the environment to recover from the impact caused by waste accumulation (Kemp et al., 2011). With the sand pre-dominating the sediment, the monitoring sites will have the potential to recover from any waste accumulation. Measurement of ORP is done to determine the organic enrichment of the sediment. In undisturbed sediment, the ORP value is about 300 to 400 mV (Winsby et al., 1996). A positive redox indicates the presence of oxygen in sediments and negative redox potential value is generally indicative of enriched organic matter. According to Colman & Holland (2000), sediment redox transition from oxic to suboxic condition occur between 150 and 300 mV, while the transition from suboxic to anoxic is between 0 and -150 mV. In the current study, the mean ORP for the farms (142 mV) and the reference site (132 mV) were all positive values (**Tables 4**), indicating the presence of oxygen in the sediment and therefore low organic enrichment.

The amount of TOC and TOM, TP and TN in sediment is useful in the determination of sediment contamination. It is estimated that for a zone to be considered as uncontaminated, the content of organic matter in the sediment must range from 0.5 to 5 %, whereas the sediments with more than 15 % organic matter are typical in contaminated zones (Méndez, 2002). The samples analyzed had TOM in the range of 4.42 –8.98 % (**Figure 5**). The results of the organic matter analysis indicated that the sampled sites ranged from uncontaminated to slightly contaminated sediments due to the organic matter content. Alpaslan & Pulatsü, (2008) observed organic matter values of 13.12–15.57 % at the cage-station sediments in Kesikköprü Reservoir in Turkey. Organic matter level of 39-69 % was determined in the rainbow trout cage culture of oligotrophic Passage Lake, Canada (Cornel & Whoriskey, 1993).

US EPA (2002) recommended assessment categories for TOC in sediments. For low impact, TOC should be less than 1 %; for intermediate impact, TOC should range 1 to 3 %, and for high impact, the TOC in sediments should be greater than 3%. The mean TOC in this study was 2.57 - 5.22 %. Based on USEPA (2002) categorization, the organic carbon levels in the analyzed sediments were of intermediate to high impact. Troell and Berg (1997) reported total carbon content of between 2.8 % and 4.49 % in the sediment of tilapia cages in tropical Kariba Lake which is similar to the present study. Temporetti et al., (2001) determined TOC levels of 0.2 % to 5.3 % in salmonid cultured sediment. Additionally, Alpaslan and Pulatsü (2008)

reported TOC levels of 5.4-8.59 % in a rainbow trout cultured reservoir. They reported that accumulation of organic matter beneath cages differed from farm to farm and mainly depended on local conditions such as hydrological, geomorphic features and production capacity. Accumulation rates were, therefore, different for different farms (Maldonado *et al.*, 2005). The accumulation of TOM and TOC in the present study were low compared to others elsewhere and showed significant differences in the sites. However, it was not clear that the tilapia cage culture influenced the accumulation of TOM and TOC in the reference site since TOM and TOC values were relatively higher at the reference site.

Total nitrogen (TN) levels of the sediment in the farm were different from the reference site and were determined to be between 0.22- 0.45 % for the farm (**Figures 5**). The levels presented are similar to the values of Troell and Berg (1997) ranging from 0.22 to 0.40 % in the tilapia cages in a tropical Lake and of Alpaslan and Pulatsü (2008) (0.26 % and 0.44 %) reported in a rainbow trout cage system. Temporetti *et al.*, (2001) recorded TN levels of 0.1-0.8 % in salmonid cage system. In this study, the maximum phosphorus level was 0.605 % for the farm. Troell & Berg (1997) observed phosphorus maximum value of 0.26 % in tilapia cage farm in a tropical Kariba Lake. The maximum TP determined in a reservoir in Turkey where rainbow trout culture is performed was 0.13 % (Alpaslan & Pulatsü, 2008). However, TP ranged from 0.2-5.3 % in salmonids cage farm in Alicura Reservoir, Argentina (Temporetti *et al.*, 2001). There were perfect correlations among TOM, TOC, and TN, suggesting they have a common source (**Tables 5**).

4.3 Metals in Water Column and Sediment

Several researchers have mentioned the buildup of metals in sediment due to aquaculture activities (Chou *et al.*, 2002; Mendiguchía *et al.*, 2006; Sutherland *et al.*, 2007). For example, Fe and Zn are used as additives in a fish diet. Copper is usually employed as an antifouling agent for treating cage nets [Nikolaou *et al.*, 2014]. In this study metals such as Pb, Zn, Cd, and Se were not detected in the water column. Zinc (Zn), Fe and Mn values found in the water column were very low and were below the permissible limits recommended by USEPA (1986). Similar low values of heavy metal were reported by Gordon & Ansa-Asare (2012) in the lake. The results are also consistent with a freshwater satellite Lake in Kenya where Pb and Zn were not detected in the water column and Fe, Mn and Cu levels were very low (Mwamburi, 2009). They indicated that the low levels of heavy metals might be partly due to the fact that little or no wastewater from agricultural, industrial or sewage is discharged into the lake. There were

no significant differences in metals concentrations between the farm and the reference site in the water column (Mwamburi, 2009).

The heavy metal levels observed in the sediments in this study were all lower than the threshold effects concentration (MacDonald et al., 2000). The variation in the content of the lake's sediment was shown in the metal distribution. Selvaraj *et al.*, (2004) reported that high sand and low organic contents in sediment reflect low metal concentrations. The high metal concentrations observed in the farm sediment compared to the water column may be attributable to relatively higher organic matter content in the sediment. According to Tukura et al., (2007), the level of metals in sediment increases with a corresponding increase in organic materials. Very high concentrations of Fe were found in the sediments and according to Basaran et al., (2010), apart from the feeds used in aquaculture, natural background concentrations of heavy metals may also play an important role in accumulation process of Fe and Zn in sediments. Fe usually has high natural background levels which are thousand times high in sediments. Comparing the accumulation of heavy metals in water column and sediments, it can be said that heavy metals accumulate more in sediments than water, since the sediment act as a major depository for all contaminants and dead organic matter (Nguyen *et al.*, 2005; Saeed & Shaker, 2008).

5. Conclusion

The knowledge of environmental impacts of cage culture is vital to the protection and management of aquatic resources. The results obtained revealed that the tilapia cage culture that was studied in Lake Volta did not significantly impact the quality of the lake with regards to heavy metals pollution. The results showed that the concentration of heavy metals in the water column and sediment were low and within tolerable levels suggesting no impacts from feed additives. However, the farms seemed to have a moderate effect on sediment quality with respect to organic matter which is difficult to attribute solely to impact from the cage since data on pre-farm sediment quality was non-existent. The minimal impact of the cage aquaculture could be attributed to possible dispersion of cage waste by the water currents, and reduction of nutrients by dilution. The levels of the water quality parameters (turbidity, DO, pH and conductivity) from the farm were not significantly different from those of the reference site indicating that the water quality parameters were not affected by the cage farming activity. The oxygen levels encountered during the monitoring period is suitable for tilapia production and ecosystem use. With the expansion in cage operations in the lake, nutrient loads will continue to increase and that will produce considerable pollution into the lake's environment. For

sustainable development of cage culture in Lake Volta, it would be useful for stakeholders to design a long term programme to monitor water and sediment quality.

Acknowledgment

Authors wish to acknowledge the financial contributions made by Royal Society Africa Leverhulme award (AA 120043) in support of this research work. The following technical staff: Daniel Amoah, Serapis Appiah and Emmanuel Adu-Ofori of CSIR-Water Research Institute are acknowledged. Facilities provided by CSIR-Water Research Institute are also acknowledged.

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.

Conflict of interest

The authors declare no conflict of interest in the publication of this article and have agreed on its publication in this journal.

References

- Agodzo, B. D. (2013). Changes in the ecosystem services of the Volta Lake and their impacts on local livelihoods along its catchment areas in Ghana. Norwegian University of Life Sciences, Ås.
- Akongyuur, D., Ofori-Danson, P. K., & Nunoo, F. (2012). Selectivity and fish catches of gillnets in stratum VII (Yeji sector) of Lake Volta for sustainable management.
- Akrasi, S. A. (2005). The assessment of suspended sediment inputs to Volta Lake. *Lakes & Reservoirs: Research & Management*, 10(3), 179-186.
- Alpaslan, A., & Pulatsü, S. (2008). The effect of rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) cage culture on sediment quality in Kesikköprü Reservoir, Turkey. *Turkish Journal of Fisheries and Aquatic Sciences*, 8(1), 65-70.
- Allison, L. (1965). Organic Carbon. In C.A. Black (ed.) *Methods of soil analysis-Agronomy*: 1367-1378.
- Amakye, J. (2001). Some observations on macro-invertebrate benthos of Lake Volta at Yeji Area (Stratum VII) Thirty years after impoundment. *West African Journal of Applied Ecology*, 2(1).
- Amin, M., & Flowers, T. H. (2004). Evaluation of Kjeldahl digestion method. *J. Res. Science*, 15, 159-179.
- APHA, AWWA, WEF. (2012). Standard methods for the examination of water and wastewater, 22nded. Washington. DC, American Public Health Association, American Water Works Association and Water Environment Federation.

- Asiedu, B., Nunoo, F., & Iddrisu, S. (2017). Prospects and sustainability of aquaculture development in Ghana, West Africa. *Cogent Food & Agriculture*, 3(1), 1349531.
- Asmah, R., Karikari, A., Abban, E., Ofori, J., & Awity, L. (2014). Cage fish farming in the Volta lake and the lower Volta: Practices and potential impacts on water quality. *Ghana Journal of Science*, 54(1), 33-47.
- Basaran, A. K., Aksu, M., & Egemen, O. (2010). Impacts of the fish farms on the water column nutrient concentrations and accumulation of heavy metals in the sediments in the eastern Aegean Sea (Turkey). *Environmental monitoring and assessment*, 162(1-4), 439-451.
- Belias, C. V., Bikas, V. G., Dassenakis, M. J., & Scoullos, M. J. (2003). Environmental impacts of coastal aquaculture in eastern Mediterranean bays the case of Astakos Gulf, Greece. *Environmental Science and Pollution Research*, 10(5), 287.
- Béné, C. (2007). Diagnostic study of the Volta Basin fisheries Part 1: Overview of the fisheries resources.
- Boyd, C.E., C. S. Tucker, A. McNevin, K. Bostick, & Clay, J., (2007). Indicators of resource use efficiency and environmental performance in fish and crustacean aquaculture. *Reviews in Fisheries Science* 15 (4) :327–360.
- Chen, Y. S., Beveridge, M., & Telfer, T. (1999). Settling rate characteristics and nutrient content of the faeces of Atlantic salmon, *Salmo salar* L., and the implications for modelling of solid waste dispersion. *Aquaculture Research*, 30(5), 395-398.
- Chen, Y., Beveridge, M., & Telfer, T. (2000). Derived data for more effective modeling of solid wastes dispersion from sea cage farms. Paper presented at the International Symposium on Cage Aquaculture in Asia, Tungkang, Pintung (Taiwan), 2-6 Nov 1999.
- Chou, C., Haya, K., Paon, L., Burrige, L., & Moffatt, J. (2002). Aquaculture-related trace metals in sediments and lobsters and relevance to environmental monitoring program ratings for near-field effects. *Marine pollution bulletin*, 44(11), 1259-1268.
- Colman, A. S., & Holland, H. D. (2000). The global diagenetic flux of phosphorus from marine sediments to the oceans: redox sensitivity and the control of atmospheric oxygen levels.
- Cornel, G., & Whoriskey, F. (1993). The effects of rainbow trout (*Oncorhynchus mykiss*) cage culture on the water quality, zooplankton, benthos and sediments of Lac du Passage, Quebec. *Aquaculture*, 109(2), 101-117.
- Elnabris, K. J., Muzyed, S. K., & El-Ashgar, N. M. (2013). Heavy metal concentrations in some commercially important fishes and their contribution to heavy metals exposure in Palestinian people of Gaza Strip (Palestine). *Journal of the Association of Arab Universities for Basic and Applied Sciences*, 13(1), 44-51.
- Fobil, J., & Attuquayefio, D. (2003). Remediation of the environmental impacts of the Akosombo and Kpong dams. *Horizon International, Yale University, Yale*.
- Gondwe, M.J.S., Guildford, S.J. & Hecky, R.E. (2011). Physical-chemical measurements in the water column along a transect through a tilapia cage fish farm in Lake Malawi, Africa. *Journal of Great Lakes Research*, 37, 102 – 113.
- Gordon, C., & Ansa-Asare, O. (2012). Water quality assessment of Densu, Birim and Ayensu rivers in the Okyeman area. *West African Journal of Applied Ecology*, 20(3), 53-64.
- Karikari, A., Akpabey, F., & Abban, E. (2013). Assessment of water quality and primary productivity characteristics of Volta Lake in Ghana. *Academia Journal of Environmental Sciences*, 1(5), 88-103pp.
- Kassam, L. (2014). *Aquaculture and food security, poverty alleviation and nutrition in Ghana: Case study prepared for the Aquaculture for Food Security, Poverty Alleviation and Nutrition project*: WorldFish.
- Kemp, P., Sear, D., Collins, A., Naden, P., & Jones, I. (2011). The impacts of fine sediment on riverine fish. *Hydrological processes*, 25(11), 1800-1821.

- Kingston, H., & Walter, P. (1995). Microwave assisted acid digestion of siliceous and organically based matrices. *EPA Draft Method*, 3052, 2015-12.
- MacDonald, D. D., Ingersoll, C. G., & Berger, T. (2000). Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. *Archives of environmental contamination and toxicology*, 39(1), 20-31.
- Maldonado, M., Carmona, M. C., Echeverría, Y., & Riesgo, A. (2005). The environmental impact of Mediterranean cage fish farms at semi-exposed locations: does it need a re-assessment? *Helgoland Marine Research*, 59(2), 121.
- McCartney, M., Forkuor, G., Sood, A., Amisigo, B., Hattermann, F., & Muthuwatta, L. (2012). *The water resource implications of changing climate in the Volta River Basin* (Vol. 146): IWMI.
- Méndez, N. (2002). Annelid assemblages in soft bottoms subjected to human impact in the Urías estuary (Sinaloa, Mexico). *Oceanologica Acta*, 25(3-4), 139-147.
- Mendiguchía, C., Moreno, C., Manuel-Vez, M. P., & García-Vargas, M. (2006). Preliminary investigation on the enrichment of heavy metals in marine sediments originated from intensive aquaculture effluents. *Aquaculture*, 254(1-4), 317-325.
- Mensah, E. T.-D., & Attipoe, F. K. (2013). Growth parameters and economics of tilapia cage culture using two commercial fish diets. *International Journal of Development and Sustainability*, 2(2), 825-837.
- Morrisey, D., Gibbs, M., Pickmere, S., & Cole, R. (2000). Predicting impacts and recovery of marine-farm sites in Stewart Island, New Zealand, from the Findlay–Watling model. *Aquaculture*, 185(3-4), 257-271.
- Moxon, J. (1984). Volta; man's greatest lake: the story of Ghana's Akosombo dam.
- Mwamburi, J. (2009). Trace metal concentration in water and sediments of satellite lakes within Lake Victoria (Kenya) basin. *Lakes & Reservoirs: Research & Management*, 14(3), 203-220.
- Nguyen, H. L., Leermakers, M., Osán, J., Török, S., & Baeyens, W. (2005). Heavy metals in Lake Balaton: water column, suspended matter, sediment and biota. *Science of the Total Environment*, 340(1-3), 213-230.
- Nikolaou, M., Neofitou, N., Skordas, K., Castritsi-Catharios, I., & Tziantziou, L. (2014). Fish farming and anti-fouling paints: a potential source of Cu and Zn in farmed fish. *Aquaculture Environment Interactions*, 5(2), 163-171.
- Ofori-Danson, P. (2002). Trophic relationships and spawning habits of post-impoundment fish stocks of Lake Volta in Ghana. *Ghana Journal of Science*, 42(1), 61-70.
- Ofori-Danson, P., & Ntow, W. (2005). Studies on the current state of the limno-chemistry and potential fish yield of Lake Volta (Yeji sector) after three decades of impoundment. *Ghana Journal of Agricultural Science*, 38(1), 65-72.
- Ofori, J., Abban, E., Karikari, A., & Brummett, R. (2010). Production parameters and economics of small-scale tilapia cage aquaculture in the Volta Lake, Ghana. *Journal of Applied Aquaculture*, 22(4), 337-351.
- Olalekan, E., Kies, F., Omolara, L., Rashidat, S., Hakeem, E., Latunji, A., . . . Oluwaseun, F. (2015). Effect of Water Quality Characteristics on Fish Population of the Lake Volta, Ghana.
- Saeed, S. M., & Shaker, I. M. (2008). *Assessment of heavy metals pollution in water and sediments and their effect on Oreochromis niloticus in the northern delta lakes, Egypt*. Paper presented at the 8th international symposium on Tilapia in Aquaculture.
- Sapkota, A., Sapkota, A. R., Kucharski, M., Burke, J., McKenzie, S., Walker, P., & Lawrence, R. (2008). Aquaculture practices and potential human health risks: current knowledge and future priorities. *Environment international*, 34(8), 1215-1226.

- 563 Selvaraj, K., Mohan, V. R., & Szefer, P. (2004). Evaluation of metal contamination in coastal
564 sediments of the Bay of Bengal, India: geochemical and statistical approaches. *Marine*
565 *pollution bulletin*, 49(3), 174-185.
- 566 Sutherland, T., Petersen, S., Levings, C., & Martin, A. (2007). Distinguishing between natural
567 and aquaculture-derived sediment concentrations of heavy metals in the Broughton
568 Archipelago, British Columbia. *Marine pollution bulletin*, 54(9), 1451-1460.
- 569 Temporetti, P., Alonso, M., Baffico, G., Diaz, M., Lopez, W., Pedrozo, F., & Vigliano, P.
570 (2001). Trophic state, fish community and intensive production of salmonids in Alicura
571 Reservoir (Patagonia, Argentina). *Lakes & Reservoirs: Research & Management*, 6(4),
572 259-267.
- 573 Troell, M., & Berg, H. (1997). Cage fish farming in the tropical Lake Kariba, Zimbabwe:
574 impact and biogeochemical changes in sediment. *Aquaculture research*, 28(7), 527-
575 544.
- 576 Tukura, B., Kagbu, J., & Gimba, C. (2007). Effects of pH and total organic carbon (TOC) on
577 the distribution of trace metals in Kubanni dam sediments, Zaria, Nigeria. *Science*
578 *World Journal*, 2(3).
- 579 United States Environmental Protection Agency (USEPA) (1986). Quality criteria for water.
580 EPA 440/5-86-001. May 1986. Office of water regulations and standards. Washington
581 DC, USA.
- 582 U.S. Environmental Protection Agency (EPA). (2002). Mid-Atlantic Integrated Assessment
583 (MAIA) Estuaries 1997-98: Summary Report, EPA/620/R02/003, pp. 115.
- 584 Winsby, M., Sander, B., Archibald, D., Daykin, M., Nix, P., Taylor, F., & Munday, D. (1996).
585 The environmental effects of salmon net-cage culture in British Colombia. *Report*
586 *prepared for the Ministry of Environment, Lands and Parks*, 1106-1175.

captions

Table 1: Mean \pm SD concentrations and ranges (in parenthesis) of surface, bottom and reference sites for some physico-chemical parameters in the fish farm

Table 2: Sediment particle size distribution and soil texture of the Farm

Table 3: Mean \pm SD and range of metal concentrations (mg/L) in the water column of the farm

Table 4: Mean and range of metals, ORP, and pH in the sediment of the farm

Table 5: Pearson correlation analysis between sediment variables in the farm (N=96)

Table 1

Parameter	Farm	Surface	Farm	Bottom
	Surface	reference	Bottom	reference
Temperature	28.8±0.81	28.5±0.68	27.9±0.74	27.7±0.63
(° C)	(27.1-30.7)	(27.0-29.7)	(26.5-28.9)	(26.7-28.6)
pH	-	-	-	-
	(6.4-8.7)	(6.6-8.8)	(4.2-8.5)	(6.6-8.5)
Conductivity	64.3±4.6	62.3±4.8	65.6±6.1	62.2±3.8
(µS/cm)	(57.5-72.7)	(57.7-73.8)	(57.5-79.8)	(58.5-71.2)
DO	6.5±0.9	6.9±1.0	3.0±1.3	2.7±1.4
(mg/L)	(5.4-8.4)	(5.5-8.7)	(0.9-4.6)	(0.8-4.4)
Turbidity	2.2±0.8	2.1±1.1	3.0±1.6	2.9±2.4
(NTU)	(0.5-3.4)	(0.5-4.0)	(0.6-5.7)	(0.6-8.5)

Table 2

Farm	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Texture
Farm	0.138±0.87 (0.0 – 7.76)	57.3±8.96 (32.0 – 75.3)	20.0 ± 3.95 (10.7 – 31.2)	22.5 ± 5.57 (12.6 – 49.8)	Sandy clay loam
Ref.	0.011±0.027 (0.0 – 0.10)	60.4±6.54 (47.9 – 81.2)	18.8±3.68 (3.78 -23.9)	20.8 ± 3.05 (15.0 – 28.2)	Sandy clay loam

Table 3

Metals	Farm Surface	Surface Reference	Farm Bottom	Bottom Reference	*Permissible limits
Pb	ND	ND	ND	ND	0.05
Zn	0.009 ±0.024 (0.0 – 0.226)	0.027 ±0.024 (0.0- 0.336)	0.007±0.016 (0.0 – 0.11)	0.017±0.016 (0.0 – 0.12)	1.0
Cu	0.001	ND	ND	ND	1.0
Cd	ND	ND	ND	ND	0.01
Fe	0.085±0.131 (0.0 - 0.992)	0.182 ± 0.203 (0.0 – 2.10)	0.178 ±0.301 (0.0 - 3.03)	0.294 ±0.312 (0.0 – 1.70)	1.0
Mn	0.029 ± 0.038 (0.0 – 0.255)	0.039 ±0.031 (0.0 – 0.318)	0.114 ± 0.203 (0.0 – 2.06)	0.161±0.203 (0.0 – 0.83)	0.05
Se	ND	ND	ND	ND	-

*Permissible limits according to USEPA (1986) ND: not detected

Detection limits for Pb = 0.005 mg/L, Cu = 0.02 mg/L, Cd = 0.002 mg/L, Se = 0.001 mg/L

Table 4

Parameter	Farm	Reference	*TEC
ORP	142	132	-
(mV)	(14.2 – 200)	(67.1 – 184)	
pH	-	-	-
	(3.93 – 7.23)	(4.35 – 6.39)	
Pb	1.98	0.76	35.8
(mg/kg)	(0.0 – 15.0)	(0.0 – 10.5)	
Zn	133.0	90.5	121
(mg/kg)	(0.0 -949.0)	(24.9 – 208.0)	
Cu	35.7	40.4	31.6
(mg/kg)	(0.0- 74.3)	(7.25 – 67.5)	
Cd (mg/kg)	ND	ND	0.99
Fe	38659	37917	188,400
(mg/kg)	(51 -474270)	(4386 – 320024)	
Mn	1966	3136	630
(mg/kg)	(47 -11283)	(150 – 9185)	
Se	0.52	0.34	-
(mg/kg)	(0.00 – 1.77)	(0.00 – 0.75)	

*TEC = Threshold effect concentration (MacDonald *et al.*, 2000) ND = Not detected

Detection limit for Cd = 0.20 mg/kg; ORP = Oxidation Reduction Potential

Table 5

	TOC	TOM	TN	TP	ORP	pH
TOC	1					
TOM	1.000**	1				
TN	.999**	.999**	1			
TP	-.122	-.123	-.120	1		
ORP	-.041	-.037	-.044	-.142	1	
pH	.136	.144	.145	.147	.063	1

**Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

TOC = total organic carbon; TOM = total organic matter; TN = total nitrogen; TP = total phosphorus

Captions

Figure 1: Map of Lake Volta in Ghana, showing the location of the Farm

Figure 2: A picture of the Farm on Lake Volta

Figure 3: Sampling stations at Farm in Volta Lake, Ghana

Figure 4: Variation of particle size content in the sediment of the farm and its reference **sites** in the Lake during the monitoring period

Figure 5: Variations of TOC, TOM, TN and TP contents in the sediment of the farm and the reference site (TOC-Ref., TOM-Ref., TN-Ref., TP-Ref.) in the Lake Volta.

Figure 1

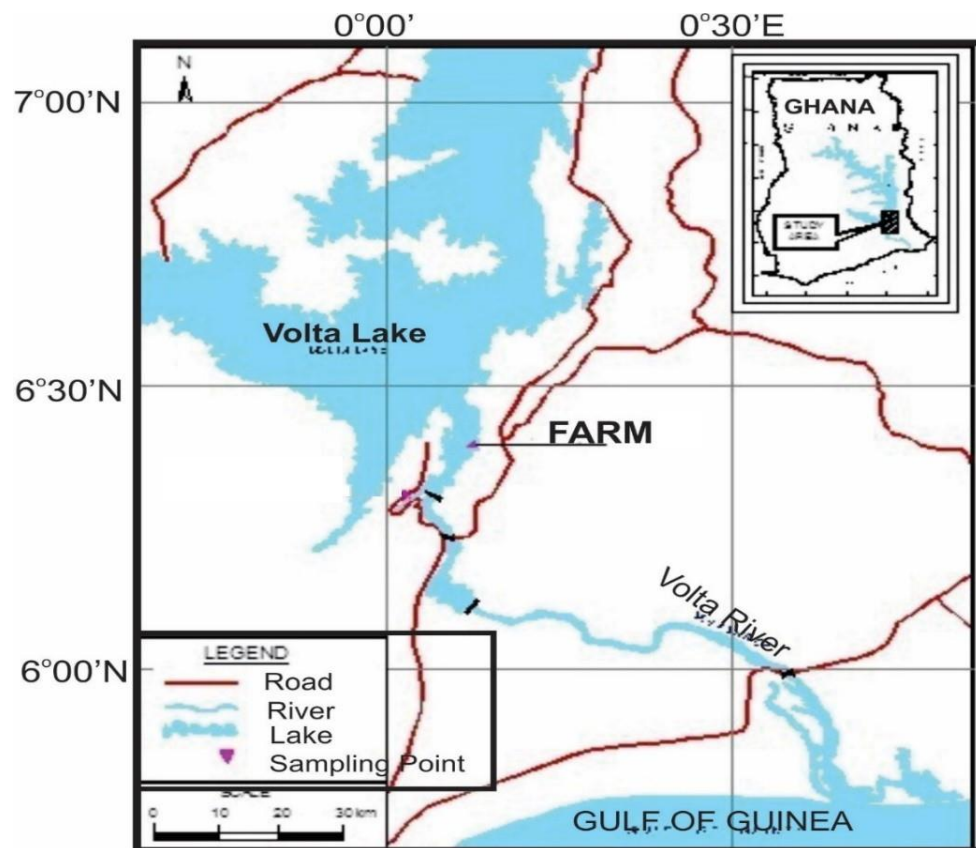


Figure 2



Figure 3



Figure 4

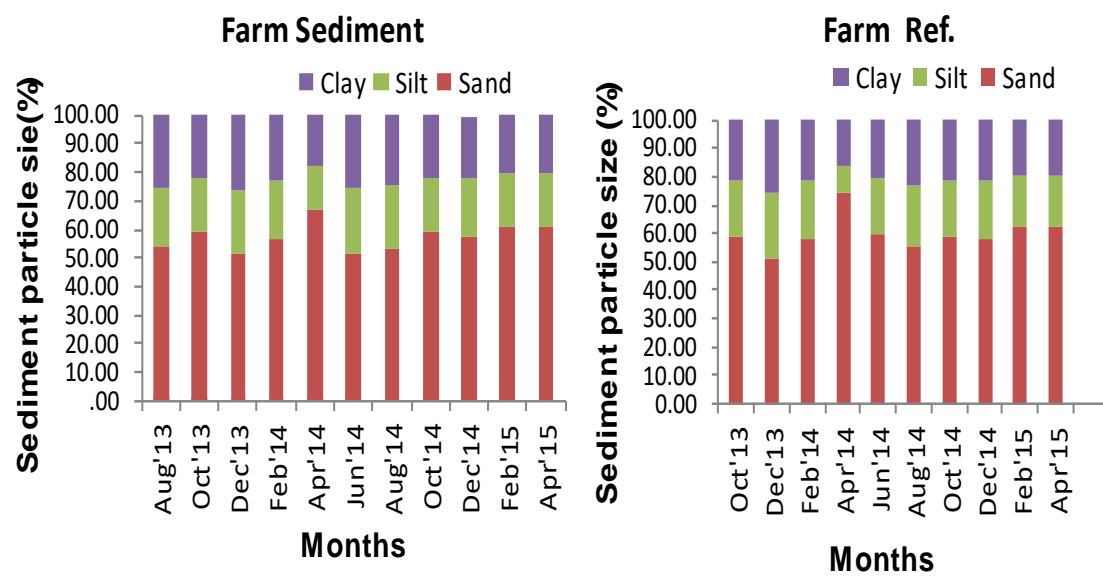


Figure 5

