

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

44

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

50

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

59

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

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

78

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

84

85 **2. Material and Methods**

86 **2.1 The Study Area (Lake Volta)**

87 The lake lies between longitude 1° 30'W and 0° 20'E, and latitude 6° 15'N and 9° 10'N (**Figure**
88 **1**). At the highest level, it has a surface area and a volume of approximately 8,500 km² and 149
89 km³ respectively, with 400 km length. It has a mean depth of 19 m and represents about 3.6%
90 of Ghana's surface area (Moxon, 1984).

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

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

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

106 <Figure 1>

107

108 **2.1.1 Description of the fish farm**

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

119 <Figure 2>

120 **2.2 Sampling**

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

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

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

133

<Figure 3>

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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

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

169

170 **2.4.3 Sediment Total Phosphate**

171 The sediment samples were oven-dried and 0.3g of the dried sample was digested using HNO₃
172 (8ml, 65%) and HF (2ml, 40%) mixture in a 'milestone' Ethos microwave digester (START
173 D) at 180° C for 45 min. The solution was diluted to the 50 ml mark and left overnight to
174 promote precipitation of suspended solids. Then, the digested sample (0.5 ml) was pipetted into
175 a 50 ml flask followed by its dilution to 25 ml. The phosphate determination was performed at
176 880 nm using T 60 UV-Visible spectrophotometer following molybdate complex formation
177 and reduction with H₃BO₃ (APHA, AWWA, WEF, 2012).

178

179 **2.4.4 Particle Size Analysis- Sieve Method**

180 Empty laboratory test sieves of 200 mm diameter with the following mesh sizes in the order:
181 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
182 on a shaker. Pre-weighed sediment samples were poured into the 5 mm sieve, covered and the
183 shaker turn on for 5 min. The sediment weight remaining in each sieve was attained by finding
184 the differences between the weights of the sieves containing the sediments and the empty
185 sieves. In order to determine the percentage sediment retained on each sieve, the weight of the
186 sediments retain on the sieves were divided by original weights of the sediments.
187 Categorization of the sediment types was done using the United States Department of
188 Agriculture (USDA) textural soil chart.

189

190 **2.4.5 Oxidation Reduction Potential (ORP) Determination**

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

194

195 **2.4.6 Determination of Metals concentration in Water Column**

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

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

202

203 **2.4.7 Determination of Metals concentration in Sediment**

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

211

212 **2.5 Quality assurance and quality control**

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

217

218 **2.6 Statistical Analysis**

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

225

226 **2.7 Ethics statement**

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

229

230 **3. RESULTS**

231 **3.1 Water Quality Parameters**

232 The mean, standard deviation, minimum and maximum values of the water quality parameters
233 at the study area are presented in **Tables 1**. Surface water temperatures were found to be
234 uniform at all sampling sites and exhibited temporal variations. The pH values of the surface
235 water ranged from 6.4 to 8.7 and those of the reference site varied between 6.6 and 8.8. For the
236 bottom water, the pH values were in the range of 4.2 to 8.5 while the range of the reference
237 bottom water was 6.6-8.5. The surface water conductivity values recorded varied from 57.5-
238 72.7 μ S/cm and that of the reference was 57.7-73.8 μ S/cm with a mean of 62.3 \pm 4.8.
239 Conductivity values for the bottom water and reference sites were 57.5-79.8 and 58.5-71.2,
240 respectively. DO concentration in the surface water of the farm varied between 5.4-8.4 mg/L
241 and that of the reference site ranged from 5.5-8.7 mg/L. The bottom water DO values were 0.9-
242 4.6 mg/L for the farm with a mean of 3.0 \pm 1.3 and 0.8-4.4 for the reference with a mean of
243 2.7 \pm 1.4. The DO profiles were characterized by upper oxygenated water and deeper lower DO
244 waters. Turbidity values at Farm varied from 0.5 to 3.4 NTU at the surface, 0.6 to 5.7 NTU at
245 the bottom.

246 <Table 1>

247 **3.2 Sediment Particle Size and ORP**

248 The sediment samples obtained from all the sites were categorized as sandy clay loam with
249 sand being the predominant texture. Sand values ranged from 32.0 to 75.3 %; and 47.9 to 81.2
250 % at the reference site. The silt varied from 10.7 to 31.2 while 26.0 \pm 4.57 % was measured as
251 the highest clay content (**Table 2**). A major difference ($p < 0.05$) was observed for sand, silt,
252 and clay between the farm and the reference site, although sediment oxidation-reduction
253 potential (ORP) and gravel did not exhibit any significant difference. ORP values ranged from
254 14.2 to 200 mV (**Table 4**). The sediment's pH varied between 3.93 to 7.23 at the farm and 4.35
255 to 6.39 at the reference site (**Table 4**). The differences in particle sizes of the sediments in the
256 farm and the reference site of the lake are also presented in **Figure 4**.

257
258 <Table 2>

259 <Figure 4>

260 **3.3 Metal Concentrations in the Water Column**

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

265 of the metal concentrations detected in the water column was as follows: Fe > Mn > Zn > Cu
266 = Pb = Se = Cd. No significant difference was observed between the farm and the reference
267 site as far as the metals' concentrations are a concern. Nevertheless, a correlation existed
268 between Zn and Mn ($r = 0.315$, $p < 0.01$), Fe and Mn ($r = 0.509$, $p < 0.01$) and Fe and Zn ($r =$
269 0.664 , $p < 0.01$), in the farm.

270 <Table 3>

271

272 3.4 Metal Concentrations in Sediments

273 **Table 4** contains the results of the metals concentrations determined in the sediment samples
274 of both the sampling and the reference sites. Contrary to the result of the water column, a
275 considerable number of metals with appreciable concentrations, with the exception of Cd, were
276 determined in the farm and its reference site. Iron (Fe), was the metal with the highest
277 detectable concentration in both the farm (mean of 38,659 mg/kg) and the reference site
278 (37,917 mg/kg). The degree to which the metals occur in the bottom sediment is presented in
279 the following order: Fe > Mn > Zn > Cu > Pb > Se > Cd. Overall, the metals concentrations
280 determined (in the sediments) were lower than the threshold effect concentration (MacDonald
281 *et al.*, 2000). Substantial differences existed in the concentrations of Cu, Pb, Mn, and Zn
282 between the farm and the reference site.

283 <Table 4>

284 3.5 Total Organic Carbon (TOC), Total Organic Matter (TOM), Total Nitrogen (TN) and 285 Total Phosphate (TP) in Sediments

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

296 TN values varied from 0.222 to 0.450 % and from 0.335 to 0.605 % at the farm and the
297 reference site, respectively (**Figure 5**). TN showed significant differences between the
298 sampling sites (ANOVA, $p < 0.05$). TP could not be measured on the sediment samples during
299 the first year of the study. However, TP determinations were performed on the sediments from
300 June 2014 to April 2015. The TP levels ranged from 0.100 to 0.605 % and from 0.024 to 0.325
301 % at the reference site. There was no significant difference between the sampling sites for TP.

302 <Figure 5>

303 <Table 5>

304 305 **4. DISCUSSION**

306 **4.1 Water Quality Parameters**

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

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

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

324
325

326 **4.2 Sediment Quality**

327 The particle size analysis showed that the texture of the sediment was sandy clay loam at all
328 the sampling sites (**Figure 3**). The sand content in the sediments analyzed had a range of 31.5
329 – 81.2 %. The larger the diameter of sediment particles, the higher the ability of the
330 environment to recover from the impact caused by waste accumulation (Kemp et al., 2011).
331 With the sand pre-dominating the sediment, the monitoring sites will have the potential to
332 recover from any waste accumulation. Measurement of ORP is done to determine the organic
333 enrichment of the sediment. In undisturbed sediment, the ORP value is about 300 to 400 mV
334 (Winsby et al., 1996). A positive redox indicates the presence of oxygen in sediments and
335 negative redox potential value is generally indicative of enriched organic matter. According to
336 Colman & Holland (2000), sediment redox transition from oxic to suboxic condition occur
337 between 150 and 300 mV, while the transition from suboxic to anoxic is between 0 and -150
338 mV. In the current study, the mean ORP for the farms (142 mV) and the reference site (132
339 mV) were all positive values (**Tables 4**), indicating the presence of oxygen in the sediment and
340 therefore low organic enrichment.

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

351 US EPA (2002) recommended assessment categories for TOC in sediments. For low impact,
352 TOC should be less than 1 %; for intermediate impact, TOC should range 1 to 3 %, and for
353 high impact, the TOC in sediments should be greater than 3%. The mean TOC in this study
354 was 2.57 - 5.22 %. Based on USEPA (2002) categorization, the organic carbon levels in the
355 analyzed sediments were of intermediate to high impact. Troell and Berg (1997) reported total
356 carbon content of between 2.8 % and 4.49 % in the sediment of tilapia cages in tropical Kariba
357 Lake which is similar to the present study. Temporetti et al., (2001) determined TOC levels of
358 0.2 % to 5.3 % in salmonid cultured sediment. Additionally, Alpaslan and Pulatsü (2008)

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

367 Total nitrogen (TN) levels of the sediment in the farm were different from the reference site
368 and were determined to be between 0.22- 0.45 % for the farm (**Figures 5**). The levels presented
369 are similar to the values of Troell and Berg (1997) ranging from 0.22 to 0.40 % in the tilapia
370 cages in a tropical Lake and of Alpaslan and Pulatsü (2008) (0.26 % and 0.44 %) reported in a
371 rainbow trout cage system. Temporetti *et al.*, (2001) recorded TN levels of 0.1-0.8 % in
372 salmonid cage system. In this study, the maximum phosphorus level was 0.605 % for the farm.
373 Troell & Berg (1997) observed phosphorus maximum value of 0.26 % in tilapia cage farm in
374 a tropical Kariba Lake. The maximum TP determined in a reservoir in Turkey where rainbow
375 trout culture is performed was 0.13 % (Alpaslan & Pulatsü, 2008). However, TP ranged from
376 0.2-5.3 % in salmonids cage farm in Alicura Reservoir, Argentina (Temporetti *et al.*, 2001).
377 There were perfect correlations among TOM, TOC, and TN, suggesting they have a common
378 source (**Tables 5**).

379 **4.3 Metals in Water Column and Sediment**

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

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

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

408 **5. Conclusion**

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

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

426

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433

434 **Author contributions**

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

438

439 **Conflict of interest**

440 The authors declare no conflict of interest in the publication of this article and have agreed on
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442

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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

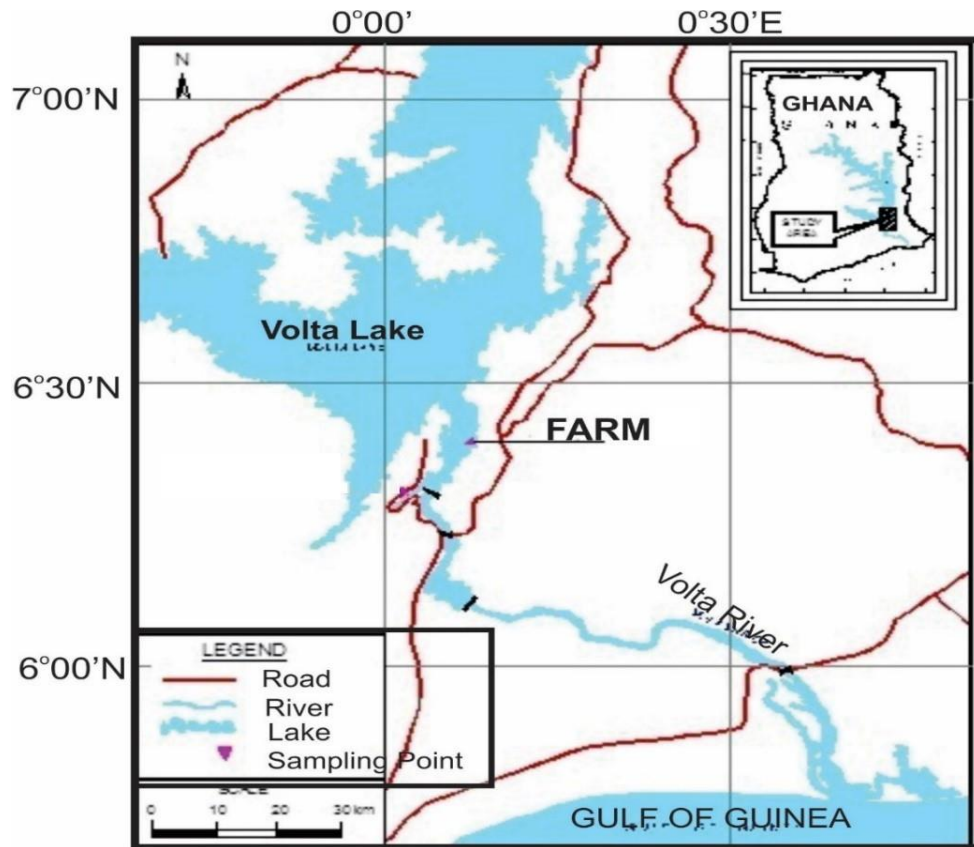


Figure 2



Figure 3



Figure 4

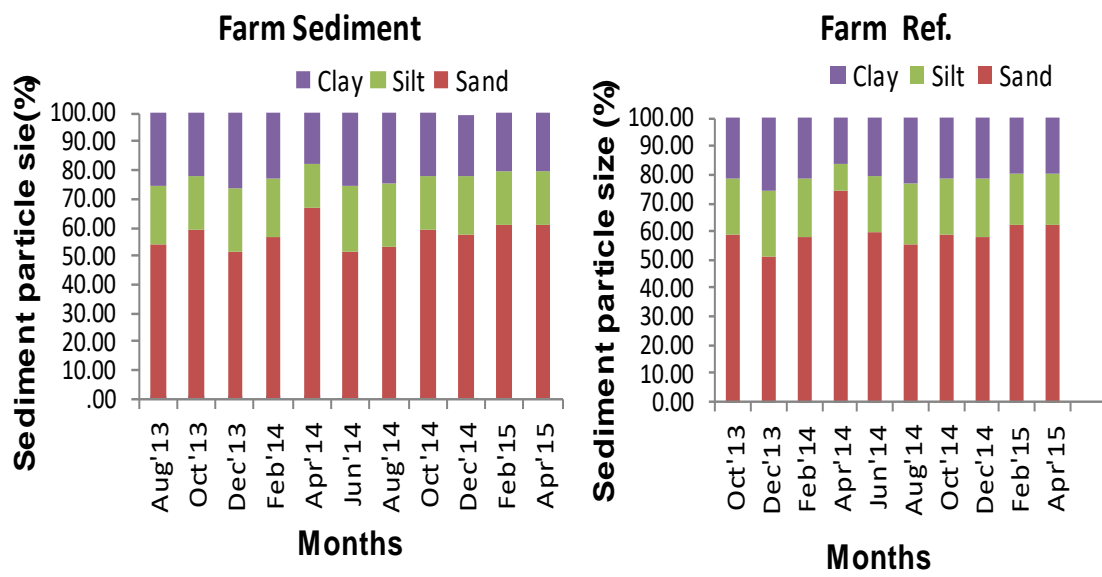


Figure 5

