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Impact of Aquaculture on Water Quality in Lake Kariba, Zimbabwe

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Abstract This study investigated the water quality at the aquaculture effluent discharge points in Lake Kariba. Water samples were collected at three sites designated site 1 (Crocodile Farm effluent discharge point), site 2 (Fish Farm effluent discharge point) and site 3 (Control point) from the month of September 2011 to January 2012. Physico-chemical variables (temperature, total dissolved solids, turbidity, pH, conductivity, nitrates, ammonia, and ortho-phosphate) were measured. Turbidity, total dissolved solids, pH and conductivity were found to be significantly (ANOVA, $p<0.05$) high at aquaculture effluent discharge points compared to the control point. Relative to the World Health Organization (WHO) and Environmental Management Authority of Zimbabwe (EMA-SI) guidelines for aquatic waters, turbidity, nitrates and ammonia at site 1 and site 2 were found to exceed the maximum allowable limit (5NTU), 10 mg/L and 0.05 mg/L respectively while dissolved oxygen was below the minimum allowable limit of 5 mg/L. All other physico-chemical parameters were within the accepted range at all stations. While the physico-chemical results indicated deteriorating water quality at the discharge point due to the effluent inflow, the large water volume in Lake Kariba plays an important factor in diluting aquaculture effluent.

Keywords Aquaculture effluent; Discharge points; Water quality; Lake volume; Lake Kariba

Introduction

Exponential human population growth, economic stagnation and food security is becoming a major concern in developing countries. This population increase has caused overexploitation of natural resources such as fisheries resources in lakes and rivers in the world (World Bank, 2004; FAO, 2007). To address this overexploitation of wild fish stocks, Zimbabwe and many other countries are promoting aquaculture (Songore, 2002). Aquaculture, the farming of aquatic animals and plants, has been the world's fastest growing food production system for the past decade, with an average compound growth rate of 11.6% per year since 1984 (Tacon, 1999; Songore, 2002). Over the last decade an increase has been noted in fish and crocodile farming along Lake Kariba (Ndebele et al., 2011).

At present fish farming and crocodile farming are the major aquacultural activities in Lake Kariba (Taylor, 2010, Ndebele et al., 2011). Fish farming concentrates on the production of *Oreochromis niloticus* fingerlings which are then cage cultured to market size in the Sanyati basin of the lake (Utete

and Muposhi, 2012). Crocodile farming enterprise focuses on the production of crocodile skin, with meat as a by-product (Mugg et al., 2007). These have both grown over the years to become the biggest aquaculture enterprises in their different disciplines in Africa (Taylor, 2010). Effluent from these aquacultural activities is discharged directly into the lake. The effluent of the two enterprises is of major concern since release of nutrient rich effluent from these cultures may lead to eutrophication of the surrounding systems with negative impacts on the biodiversity and a change in the physico-chemical parameters of the receiving water body (Iwama, 1991). Although the amount of effluent may be relatively small, their significance is greater if they are highly toxic, persistent and mobile or accumulate rapidly in organisms. The effluent may also lead to localised eutrophication in inshore waters of the lake. If the discharge, which is mainly uneaten feed and animal waste products, is not carefully monitored, it will inevitably lead to the degradation of the water quality and will affect living organisms at all trophic levels especially at the area around the discharge points. Thus, the thrust of the project was to assess

the quality of water at the aquaculture effluent discharge points in Lake Kariba.

1 Results

1.1 Conductivity

Conductivity was significantly high at the discharge points compared to the control point (Analysis of variance, abbr: ANOVA, p<0.05). There was however,

no significant seasonal (monthly) difference between the two discharge points (ANOVA, p<0.05). Highest values of 196.9 mg/L in site 2 (Fish farming) and 160.79 mg/L at site 1 (Crocodile farming) were recorded during November and October, and these were within the acceptable limits of EMA and WHO standards (Table 1).

Table 1 Mean ± SD of the physical and chemical conditions of the three sampling sites in Lake Kariba (Sanyati basin) in September 2011 to January 2012

Site/Parameter	Control	LC	LH	WHO	EMA
Turbidity (NTU)	2.97±1.81	45.94±18.78	32.65±14.38	5.0	5.0
pH	8.42±0.27	7.76±0.52	7.44±0.19	6.5−9	6−9
Temperature (℃)	31.12±1.94	31.47±1.84	28.88±1.62	27.0	35.0
TDS (mg/L)	46.44±1.28	75.71±5.37	83.4±16.45	1000.0	1000.0
Conductivi ($\mu \cdot S \cdot cm^{-1}$))	93.30±1.95	141.02±20.29	166.5±34.77	1000.0	1000.0
DO (mg/L)	4.68±0.62	3.30±2.09	2.71±0.75	5.0	5.0
Nitrates (mg/L)	0.43±0.53	8.91±12.79	7.69±5.98	50.0	10.0
Ammonia (mg/L)	0.11±0.13	2.39±3.05	1.01±1.25	0.5	0.5
Ortho-phosphate (mg/L)	0.14±0.27	0.51±0.30	0.32±0.17	0.5	0.5

Note：LC=Lake Croc Discharge point (site 1); LH= Lake Harvest discharge points (site 2) and the Control (site 3)

1.2 Dissolved Oxygen

Mean levels of dissolved oxygen at all stations were lower than the minimum allowable limit (5 mg/L) for aquatic life during the study period with (Table 1). However, there was significant difference (ANOVA, p<0.05) among the sampled sites but there was no significant temporal (monthly) variation (ANOVA, p>0.05).

1.3 Temperature

Mean surface water temperature fluctuated between 28℃ and 33℃ during the entire study period. This range was above the limit of the WHO guideline of 27℃although it was within the EMA limit of 35℃ (Table 1). No significant differences in temperature were observed among the three sampling sites and among sampling periods (ANOVA, p>0.05).

1.4 Total Dissolved Solids

Solids were significantly high (ANOVA, p<0.05) at the discharge points compared to the control, but no significant temporal differences were observed during the study period (ANOVA). The total dissolved solids at discharge points were also not significantly different (ANOVA, p>0.05). The results were within the acceptable range of both the WHO and EMA guidelines (Table 1).

1.5 Turbidity

Turbidity of the water was significantly high at the

crocodile farm discharge point (Site 1) and fish farm discharge point (Site 2), with a mean of 45.9NTU and 32.7NTU respectively compared to 3NTU at the control point (Site 3) in November (ANOVA, p<0.05). There was however, no significant difference between the two discharge points and among sampling periods (ANOVA, p>0.05). Turbidity at all the discharge points exceeded the EMA and WHO maximum allowable limit of 5 mg/L in all the months during the study (Table 1).

1.6 PH

The pH ranged from 7.40 in site 1 and site 2 to 8.42 in site 3 the control (Table 1). The range was within the acceptable limits (EMA 1997; WHO, 2006). Site 1 and site 2 were significantly lower (ANOVA, p<0.05) in pH than site 3 which was more alkaline. Site 1 and site 2 however, did not have a significant difference (ANOVA, p>0.05). Seasonal/temporal variations were not significant (ANOVA, p>0.05) among the three sites.

1.7 Nutrient levels

1.7.1 Nitrate

Nitrate levels were generally high at the two discharge points (site 1 and site 2) in December and during this month the level was above the legal limit of 10 mg/L (EMA, 1997; WHO, 2006). However, the nitrate levels in site 1 and site 2 were significantly

different (ANOVA, p<0.05) from the control site (Site 3). There was no significant (ANOVA, p>0.05) temporal variations in the mean nitrates of the study area among the three sampled points.

1.7.2 Orthophosphate
Orthophosphate levels were generally low during the study. Mean orthophosphate levels at site 1 however, exceeded the local and international legal limits of 0.5 mg/L (Table 1). Statistical analysis indicated no significant difference (ANOVA, p>0.05) amongst the sampled sites and seasonal variations.

1.7.3 Ammonia
Ammoniawas generally high at site 1 and site 2 with mean levels of 1.01 mg/L and 2.39 mg/L recorded. And these values were above the maximum allowable limits (Table 1). Significant difference (ANOVA; p<0.05) were recorded between among the three sites but no significant seasonal/temporal variation (ANOVA; p>0.05) was observed between site 1 and site 2 or with seasonal variations.

2 Discussions
An increasingly significant effect of intensive fish culture is eutrophication of the water surrounding rearing pens or the rivers/lakes receiving aquaculture effluent (Tumbare, 2008). The socio-economic benefits of cage aquaculture normally came at a cost to the environment (FAO, 2007). Large scale aquaculture has been practised in Lake Kariba since the early 1970 based on the wild kapenta (*Limnothrissamiodon*, Boulanger, 1896) but has shifted towards the more economical intensive farming of tilapia fishes and crocodiles (Songore, 2002). The cost to the environment has largely been ignored as the lake is deemed large enough to self-purify (Magadza, 2011). However, the results of this study, whose main objective was to assess the water quality at the discharge points of two large scale aquaculture enterprises relative to international potable water quality guidelines, shows this assertion to be inconsistent. Of the physical-chemical parameters of water that were assessed, there was depleted dissolved oxygen, higher turbidity and excess ammonia relative to the local and international surface water effluent discharge quality guidelines (EMA-SI, 1997; WHO, 2006).

The fact that there was no significant temporal variation in the parameters (turbidity, dissolved oxygen and ammonia) may indicate the detrimental effect of aquaculture effluent inflow (Westers, 2000). The high turbidity observed at the aquaculture discharge points, which was significantly different from that recorded at the control point, indicates an increase in the concentration of suspended matters in the water as a result of effluent inflow. This finding is corroborated by the level of total dissolved solids that where significantly high at the discharge points relative to that at the control This may have negative implication on visual feeders especially predators like the tiger fish (*Hydrocynusvittatus*, Castelnau, 1816) that dominates the lake (Mhlanga, 2000, Dalu et al., 2012). Boyd (2003) reported that excessive concentration of suspended and dissolved solids might be harmful to aquatic life because they decrease water quality, inhibit photosynthetic processes and eventually lead to increase of bottom sediments and decrease of water depth.

Oxygen plays a critical role in the physiology and metabolism of aquatic organisms (Larinier, 2002; Abdel-Tawwab et al., 2007). The depleted dissolved oxygen levels recorded in this study, notably at the discharge points, could be attributed to the presence of high concentrations of degradable organic and inorganic matters in the aquaculture effluent. This degradable material is more oxygen demanding, making oxygen less available to the desirable organisms including fish (Nizzoli et al., 2005). Low DO concentrations considerably affect the survival and behaviour of aquatic organisms (Long et al., 2008). Although the effect might not be prominent now the continued pollution in the lake might mean some points become anoxic and may lead to hypoxia especially at turnover (Manganaro et al., 2009).

Nitrate levels were high at the two discharge points with the highest being recorded at site 1 which was slightly below the legal limit of 10 mg/L according to the EMA-SI guideline values (1997). The nitrate levels in site 1 and site 2 were significantly different from the control site (Site 3). This shows that aquaculture effluent may be playing a prominent role in increasing nitrate levels in the lake. There were no significant temporal variations in the mean nitrates of the study area among the three sampled points and this is attributable to the high inflows of water in Lake Kariba from its tributaries during this study period

(Mhlanga, 2000; Chifamba, 2000). Nitrate plays a vital role in the biological metabolism of aquatic organisms notably phytoplankton and macrophytes (Boyd, 2003). Concentration of nitrate production in water at any given time is a product of balance between nitrate productions through the activities of nitrifying bacteria and nitrate destruction by autotrophic assimilation and/or bacteria denitrification (Gautier et al., 2000).

The results show no significant difference in ammonia levels between site 1 and site 2, although site 1 generally had high mean ammonia values during the study period. The mean values of ammonia at the discharge points are higher than the maximum allowable local and international limits. Thus it can be concluded that the industries are producing the same quality of effluent and need the same pollution mitigation regulatory measures. Elevated concentrations of ammonia affect the respiratory systems of many animals either by inhibiting cellular metabolism or by decreasing oxygen permeability of cell membranes (Lee et al., 2008). Acute toxicity to fish may cause a loss of equilibrium, hyper-excitability, an increased breathing rate and increased cardiac output and oxygen intake, and in extreme cases convulsions, coma and death (Brown, 1995, Nhiwatiwa et al., 2011).

Although the mean values of pH, electrical conductivity, orthophosphate and temperature recorded during the study were all within the acceptable local and international range the higher values recorded at the discharged points relative to the control indicate that the aquaculture effluent at these points is distorting the lake water quality. If this discharge continues unabated and the number of aquaculture enterprises increase there could be negative implication on the lake water quality with some parts of the lake becoming eutrophic although this might be countered by the large lake volume (Tumbare, 2008).

3 Conclusion

The concentrations of most water parameters measured in this study were significantly different compared to the control point showing that the aquaculture effluent is affecting the lake water quality. Because Lake Kariba serves as a source of domestic water supply for drinking, washing, fishing and swimming, continuous discharge of improperly treated effluent industries

should be stopped as this may cause localised eutrophication and a change in the trophic structure. The industrial waste should be thoroughly monitored and processed according to local aquaculture effluent standards which are yet to be developed before its discharge into the lake in order to maintain the integrity of the Lake Kariba.

4 Materials and Methods

4.1 Study Sites and Designing

The study was conducted in Lake Kariba, Mashonaland West province of Zimbabwe on the northern eastern border with Zambia (Figure 1). Lake Kariba lies at an altitude of 484m above sea level and between altitudes 16°28′S and 18°6′S and longitudes 26°40′E and 29°03′E. Lake Kariba is a warm monomicticmeso-oligotrophic lake with three distinguishable seasons namely a hot rainy season (November-March), cool dry season (May-August) and a very hot dry season (September-November), (Timberlake, 2000). The lake is divided into five geographical and limnologically distinct basins along its axis, namely Mlibizi (basin 1), Binga (basin 2), Sengwa (basin 3), Bumi (basin 4) and Sanyati (basin 5) (Cronberg, 1997). The Sanyati basin, (study basin), is an important spawning ground for the potadromous fish species. In addition the nutrient load from the Sanyati River and its tributaries contribute significantly to the productivity of the basin (Cronberg, 1997).

4.2 Field Sampling

Monthly water sampling was carried out from September to December, 2011 in the Sanyati Basin of Lake Kariba on selected aquaculture farm discharge points. A control was selected in an un-impacted area in the lake which was on the leeward upper side of the discharge points of the crocodile and fish farms where the effect of wind and down gradient diffusion of the aquaculture effluent was deemed minimal. Samples were collected between 09:00 and 12:00 on each sampling day. Systematic distance sampling was done with sampling beginning in site 1 and terminating in site 3 following acceptable standard methods and instrumentations (APHA, 2000). At each station, the surface water temperature, turbidity, electrical conductivity, pH, total dissolved solids, percentage oxygen saturation and dissolved oxygen were measured insitu. PH dissolved oxygen and
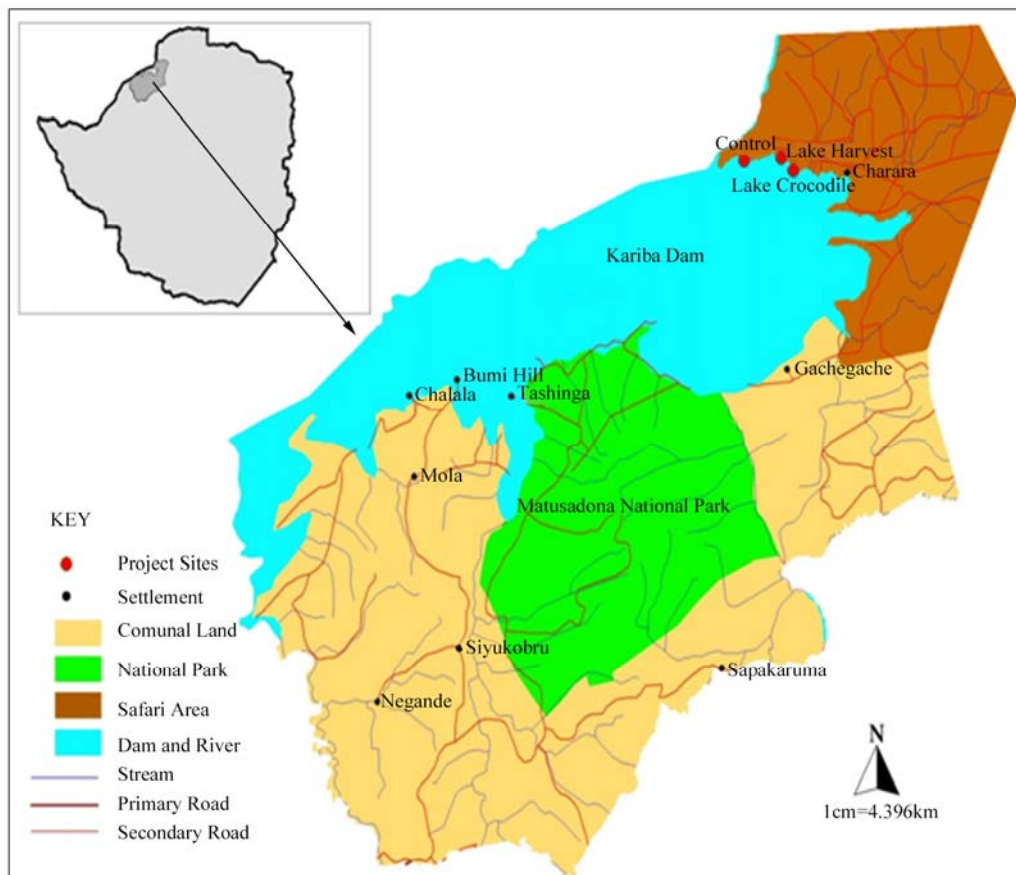
Figure 1 Location of the study sites

temperature, conductivity, total dissolved solids were measured using electronic (Ecoscan; Australia) meters. All the water test meters were calibrated before use. Surface water samples for nitrates, phosphates and ammonia analyses were collected using sterilised clean 500 mL polythene bottles. The samples were placed in a cooler box and then taken to the laboratory for analyses.

4.3 Nutrient Analysis
In the laboratory, cadmium-reduction method was used; colorimetric method (indophenols blue method) and ascorbic acid methods were used for analysis of nitrates, ammonium and orthophosphates respectively according to the procedures outlined in the Water and Wastewater Examination Manual (Adams, 1989).

4.4 Data Analysis
Variations in physicochemical characteristics of the water among sampling sites and sampling periods were examined using two-way analysis of variance (Two-way ANOVA) at 5% significance level. ANOVA was performed using the SysStat 12 for Windows version

12.02.00 (Systat, 2007). The physicochemical parameter values were compared with Zimbabwe's Environmental Management Agency (EMA) limit for surface water effluent discharge and WHO guidelines for surface water effluent discharge (EMA-SI, 1997; WHO, 2006).

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