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Effects of Aquacultural Practices on the Sediment Characteristics of Certain Type of Earthen Fishponds

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ABSTRACT

The effect of aquacultural practices on the bottom sediment quality of six selected earthen fishponds in Ife North Local Government Area of Osun State was investigated for a period of two years. The fishponds were grouped with regard to fertilization practice and water flowage regime into three sets comprising two fertilized non-flow-through ponds (FNF); two fertilized flow-through ponds (FF) and two unfertilized flow-through ponds (NFF). The investigated sediment quality parameters include color and textural composition, salinity parameters, major ions, organic parameters and heavy metals using standard methods. The parameters were not statistically different ($P > 0.05$) for the three sets of fishponds with the exception of calcium which was significantly available in the fertilized flow-through pond. The fertilized ponds were however richer in nutrient and of better drainage quality than the unfertilized ponds. The parameters with higher mean in the fertilized ponds (FNF and FF) were 16% higher on average and flow-affected parameters were 67% higher on average in the flow-through ponds (FF and NFF), of which 7.00-fold higher lead concentration contributed most to this situation. Of these parameters, cations, anions, micronutrients were found to be of highest mean concentration in fertilized flow-through ponds. However, the presence of significant levels of calcium ions as well as minimal accumulation of clay, silt and nutrients in fertilized flow ponds made this fish culture method most suitable.

Keywords: Nutrient, sediment salinity, fish culture, drainage, heavy metal

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Introduction

The pond bottom sediment is the storehouse in the pond ecosystem. Hence good bottom sediment and high-water quality are essential for successful pond management (Muendo et al. 2014). Many chemical and biological processes which occur on its surface greatly influence the water quality and the productivity of fish culture ponds (Boyd 1995). Factors associated with aquaculture practices such as liming, fertilization, exogenous feeding of fish, fish excrement, dead fish and increased vegetation also cause organic accumulation in the pond ecosystem and affect the physical and chemical properties of the bottom sediment (Boyd et al. 2002). These pollutants are preserved in the sediment over a long period dependent on their chemical persistence and physico- /bio- chemical characteristic of the sediment (Singare et al. 2011). The resultant poor sediment properties that arise through the accumulation of organic matter, nitrogen and phosphorus (Jamu and Piedrahita 2001) can lead to low dissolved oxygen, high un-ionized ammonia, high pH levels and high biological oxygen demand, leading to deterioration of pond water quality and low fish yield (Ludwig 2002). Furthermore, the decomposition processes occurring in aquatic sediments helps to recycle nutrients and during the process, elements such as nitrogen, phosphorus, iron, cobalt, and copper are interchanged between sediment and the overlying water (Tsadu 1998).

Poor fish yield is the effect of reduced pond depth (or available space for fish growth), increased microbial activities and large fluctuations in water temperature, as well as increased susceptibility of fish to diseases associated with organic matter accumulation in the pond sediment (Rahman et al.

2004; Muendo et al. 2014). The proffered solution to these problems has been removal and disposal of such pond sediment to natural system which also constitute threat to the ecosystem of the fish farm (Rahman et al. 2004). This study therefore seeks for appropriate pond management/fish culture method that would reduce organic matter accumulation in fishpond. Consequently, the study aimed at assessing the effect of pond fertilization and water flowage on the sediment characteristic of certain types of fish ponds of a commercial farm in order to ascertain the stability of the fish ponds.

Materials and Methods

Study Area

The fish ponds assessed belong to Niger Feeds and Agricultural Operations Limited (NIFAGOL), which is a commercial fishing company in Yakoyo-Origbo, Ife North Local Government Area (LGA), Osun State, Nigeria. The LGA includes primarily rural and semi-urban villages and is roughly situated on a general elevation scale of 250 to 265 m above the sea, spanning between latitudes 07 ° 25′N to 07 ° 40′N and longitudes 004 ° 25′E to 004 ° 30′E. The Shasha River (one of the largest bodies on the southwest) drains the LGA along with other water bodies such as swamps, lakes, streams and rivers of minor significance (Adedeji 2011).

The studied fish farm (NIFAGOL) established in 1984, consists of 18 ponds of varying sizes (ranging from 432 m^2 to 6383 m^2), each of which is rectangular in shape and usually shallow (Adedeji 2011). Water supply to the ponds comes from a reservoir (2 hectare surface area) located within the farm. The aquaculture activities on the farm were in semi-intensive form in which some ponds received organic fertilizers in the form of chicken drop and cow dung and the rest receiving inorganic fertilizers (NPK). Fish stocked in all ponds were supplemented by additional feed (pelleted feed) at a rate of 3% of their body weight twice a day. The feed was produced locally out of a combination of corn, soybeans, fishmeal, millet, palm kernel cake, groundnut cake, kernel-palm oil and the brewer waste. The water retention period for the fertilized non-flow-through ponds was six months and the unfertilized flow-through ponds were not drained. Fish stock density in all the culture ponds was 3 fish/m^2. In the majority of ponds, *Clarias gariepinus* are monocultured and it was polycultured with *Oreochromis niloticus* in the flow-through ponds (Table 1).

Sample Collection and Analysis

Of the eighteen ponds in NIFAGOL fish farm, only ten ponds were operational during the study. Sediment samples for sediment characteristic determinations were collected from six (Table 1) of these ten ponds bimonthly over an annual seasonal cycle from November 2006 to October 2007. The analysis composed of t hree sets of ponds, based on existing cultural practice, with regard to fertilizer treatment and water flow. The first sets of two ponds were fertilized non-flow-through ponds (FNF) and received organic and inorganic fertilizers. The second sets of two ponds were fertilized flow-through ponds (FF) and received organic and inorganic fertilizers. The third sets of two ponds were unfertilized flow-through ponds (NFF) and received no fertilizer (Adedeji 2011). Sediment samples were taken bimonthly using an improvised mud grabber (metallic plates of cross-sectional area of 15.2 by 15.2 cm).

The sediment samples were transferred to the laboratory, air dried and crushed with a pestle in a porcelain mortar. Then, they were sieved through a 2 mm mesh, before the analysis of selected physico-chemical parameters, carried out based on Boyd (1995) and Chapman (1996). Colour, particle size analysis, textural composition was done according to procedure of Bouyoucos (1962) and Shields et al. (1966). pH, organic matter, nitrate, magnesium, sodium, potassium, aluminium ion acidity, hydrogen ion acidity, pH, sulphate and phosphate levels in the sediment were determined according to Boyd (1995) and Ademoroti (1996). While some selected heavy metals (nickel, manganese, lead, copper, arsenic, iron, cobalt and chromium) were assessed by digesting 5 g of the sediment sample with dilute double acid solution (0.05 N HCl + 0.025 N H_2SO_4) (Boyd 1995). The resultant solution from the digest was analyzed for heavy metals using atomic absorption spectrophotometer (AAS PG-990 model) at appropriate wavelengths (Boyd 1995). The metals analyzed were nickel (232.0 nm), manganese (279.5 nm), lead (283.3 nm), copper (324.7 nm), arsenic (193.7 nm), iron (248.3 nm), cobalt (240.7 nm), and chromium (357.9 nm). Data obtained subjected to two-way analysis of variance (ANOVA) using SPSS software (Version 21; SPSS Inc. 2012) with fertilization and water flowage as the main factors and season (Dry and Rainy Season) as sub-factor.

Table 1. Description of fish ponds in NIFAGOL Farm

Variable	Unit	1	2	3	4	5	6
Year of impoundment		1984	1984	1984	1984	1984	1984
Outline shape	**-**	**Rectangular**	**Rectangular**	**Rectangular**	**Rectangular**	**Rectangle**	**Rectangle**
Dam size	**-**	**Small**	**Small**	**Small**	**Small**	**Small**	**Small**
Apporx. Surface Area	m^2	5550	3445	1325	4875	2275	1135.5
Apporx. Volume	m^3	13875	8612.5	1987.5	12187.5	3412.5	1703.25
Stock density	At 3 fish/m^2	16650	10335	3975	14625	6825	3305
Water Retention	Month(s)	6 (Non flow-through)	6(Non flow-through)	Flow through	Flow through	Flow through	Flow through
Cropping frequency	/ year	Twice	Twice	Not fixed (As required)	Not fixed	Not fixed	Not fixed
Fertilization Before stocking		NPK or Organic fertilizer	NPK or Organic fertilizer	NPK or Organic fertilizer	Not fertilized	Not fertilized	NPK or Organic fertilizer
Feeding frequency	/ day	Twice	Twice	NA	NA	NA	NA
Modifications done after impoundment		Refilling of caves and Excavating using bulldozer	Refilling of caves and Excavating using bulldozer	NA	NA	NA	NA
Duration of culture	Month(s)	6	6	Thru' out the year	Thru' out the year	Thru' out the year	Thru' out the year
Type of feed used		Pellets	Pellets	Pellets	Pellets & Brewer's waste	Pellets	Pellets
Type of fish being reared in the pond		*Clarias sp*	*Clarias sp*	*Clarias*/(Brooders)	*Tilapia & Clarias*	*Channa & Clarias*	*Channa & Clarias*
Al (mT)		254/255	256/255	250/251/254	256/257/259	258/258	254/256
Latitude (^{0}N)		07^0 32.379′ 07^{0}32^{0}402′	07^{0}32.413′ 07^{0}32.432′	07^{0}32.462′ 07^{0}32.468′ 07^{0}32.433′	07^{0}32449′ 07^{0}32434′ 07^{0}32471′	07^{0}32.412′ 07^{0}32.425′	07^{0}32423′ 07^{0}32395′
Longitude(^{0}E)		004^{0}26.786′ 004^{0}26.769′	004^{0}26.770′ 004^{0}26.742′	004^{0}26.770′ 004^{0}26.781′ 004^{0}26.801′	004^{0}26.842′ 004^{0}26.812′ 004^{0}26.790′	004^{0}26.826′ 004^{0}26.856′	004^{0}26.793′ 004^{0}26.800′

The means were separated using Tukey post-hoc test and differences were consider significant at significance level of 0.05. Inter-relationship among/between the three sets of ponds studied was determined using PAST (Paleontological Statistics) Statistical software version 2.12 (Hammer et al. 2001).

Results

The sediments of the investigated ponds showed various colors (Table 2) ranging from reddish brown, grayish brown, yellowish brown, dark brown to olive yellow. The sediments of the fertilized ponds ranged from greyish brown to very dark brown whereas the non-fertilized ponds ranged from yellow to red with very weak red and olive yellow coloration in April and June 2007 respectively (Table 2). As a result, the non-fertilized ponds' sediment had the lowest hue of 2.5 YR, whereas the fertilized ponds' sediment hues were typically 10 YR with a low of 5 YR. However, at the end of the fish culture period, the non-fertilized pond (precisely pond 6) had darker sediment.

Each of the investigated factors (fertilization and flowage) had effect on 12 out of 24 parameters considered (Table 3). The 12 parameters with higher mean in the fertilized ponds (FNF and FF) were on the average 1.16 times (16 percent) (1.01–1.47) higher than the unfertilized pond. Among these were the nutrient parameters (Nitrate, phosphate and organic matter/carbon) (1.05 times) and associated percentage silt and clay as well as few heavy metals (Ni, As, Cr) (1.13 times) and cations (Na^+, Mg^{2+}, H^+) (1.31times) (Table 3). Flowage, on the other hand, had effect on both cations and anions (K^+, Ca^{2+}, Al^{3+}, SO_4^{2-}) (1.32 times), Heavy metals/Micronutrients (Fe, Mn, Cu, Co, Pb) (2.34 times) and percentage sand. These parameters were on the average 1.67 (67%) (1.01 – 7.00 times) higher in the flow-through ponds (FF and NFF) than non-flow-through ponds (FNF) with lead (7.00 times) having the greatest contribution to flowage effect (Table 3). Aluminum ion, potassium, lead and iron were discovered to have higher mean of approximately 17 percent (1.01-1.56 times) in non-fertilized flow-through ponds than fertilized flow-through (Table 3).

With the exception of copper and manganese, the heavy metals were mostly less than 1 mg/100 g and their order of dominance was Mn > Cu > Fe > As> Ni > Pb > Co > Cr. While the cationic order of dominance was in two patterns with either calcium or hydrogen ion dominating in each case. The order was $Ca^{2+} > H^+ > Mg^{2+} > Al^{3+} > Na^+ > K^+$ (ponds 2, 3, 4, 5 and 6) and $H^+ > Ca^{2+} > Mg^{2+} > Al^{3+} > Na^+ > K^+$ (pond 1). The anionic order of dominance was also in two slightly different pattern due to sulphate or phosphate ion dominance, resulting in $SO_4^{2-} > PO_4^{3-} > NO_3^{2-}$ (ponds 2, 3, 5 and 6) or $PO_4^{3-} > SO_4^{2-} > NO_3^{2-}$ (ponds 1 and 4).

For 13 of the investigated parameters, the pattern of seasonal variations in the three sets of ponds seemed to be similar. Phosphate, sulphate, chromium, pH (water/$CaCl_2$) and aluminum/hydrogen ion showed higher mean values in the rainy season for all ponds.

Whereas potassium, nitrate, organic matter/carbon, nickel, manganese and lead had higher mean values in the dry season (Table 4). The percentage sand and clay content of the sediment, as well as the sodium level, showed significant seasonal variation, with the highest mean for these parameters recorded in fertilized non-flow-through ponds (FNF) (Table 4). The effect of pond fertilization was further observed in the mean values of percent silt, percent clay, sodium, magnesium, nitrate, organic matter/carbon, nickel, copper and iron which were higher in the fertilized non-flow-through ponds during the dry season. Similarly, during the rainy season, the percentage sand, pH (water), and phosphate had the highest mean in FNF. Seasonal variation due to flowage was observed for calcium, manganese, and cobalt levels in sediment, which were highest in fertilized flow-through ponds (FF) during the dry season and sulphate during the rainy season. Furthermore, during the dry season, the highest detectable level of lead (0.24 mg/100g) was found in the non-fertilized flow-through pond. The overall t-test of the seasonal variation patterns of the investigated parameters confirmed significant variation for phosphate, nickel and manganese concentrations in the ponds' sediment, with phosphate concentration depicting highly significant differences (Table 5). Moreover, the concentration of phosphate, sulphate, nickel, manganese, lead and copper in the sediment were higher than the levels measured in reservoir inlet water (Table 6). Whereas water soluble and essential nutrients like sodium, potassium, calcium, nitrate and arsenic were not as concentrated in the sediment.

Based on the mean values of the studied variables, the Euclidean distance (similarity index) was used to test for correlation between the sets of ponds. The index revealed that the flow-through ponds (FF and NFF) were more similar than the fertilized ponds (FF and FNF). Furthermore, cluster analysis of the pond sets based on the mean values of the investigated parameters produced two clusters, with flow-through ponds (FF and NFF) separated from non-flow-through ponds (FNF) (Figure 1).

Table 2. Monthly variation in colour and textural composition of the investigated NIFAGOL fish pond sediments over the period of study

Cultural Practice	Parameters	FNF		FF		NFF	
Sampling Station		**1**	**2**	**3**	**4**	**5**	**6**
Month							
November 2006	Value / Chroma	3 / 2	NOT In Use	4 / 4	3 / 2	2.5 / 2	NOT In Use
	Hue (YR)	5		5	5	5	
	Color	Dark Reddish Brown		Reddish Brown	Dark Reddish Brown	Dark Reddish Brown	
	Sediment Type	Clayey Sand		Silty Sand	Silty Sand	Silty Sand	
February 2007	Value / Chroma	3 / 3	5 / 3	4 / 2	2 / 2	5 / 8	3 / 6
	Hue (YR)	10	10	10	10	10	10
	Color	Dark Brown	Brown	Greyish Brown	Dark Brown	Yellowish Brown	Yellowish Brown
	Sediment Type	Silty Mud	Silty Mud	Silty Sand	Silty Sand	Sandy Mud	Silty Sand
April 2007	Value / Chroma	NOT In Use	NOT In Use	2 / 2	3 / 3	3 / 3	6/ 8
	Hue (YR)			10	10	10	2.5
	Color			Very Dark Brown	Dark Brown	Dark Brown	Olive Yellow
	Sediment Type			Sandy Mud	Sand	Silty Sand	Silty Mud
June 2007	Value / Chroma	3 / 3	NOT In Use	5 / 2	3 / 6	5 / 2	7 / 6
	Hue (YR)	10		7.5	10	2.5	10
	Color	Dark Brown		Brown	Dark Yellowish Brown	Weak Red	Yellow
	Sediment Type	Silty Sand		Silty Sand	Silty Sand	Clayey Sand	Silty Mud
August 2007	Value / Chroma	NOT In Use	3 / 4	NOT In Use	NOT In Use	6 / 8	2 / 2
	Hue (YR)		10			10	10
	Color		Dark Yellowish Brown			Brownish Yellow	Very Dark Brown
	Sediment Type		Sand			Silty Mud	Silty Sand
October 2007	Value / Chroma	NOT In Use	3 / 6	3 / 6	3 / 6	3 / 6	2 / 2
	Hue (YR)		10	10	10	10	10
	Color		Dark Yellowish Brown	Dark Yellowish Brown	Dark Yellowish Brown	Dark Yellowish Brown	Very Dark Brown
	Sediment Type		Sand	Sand	Sand	Silty Sand	Sand

Table 3. Mean values of the pond sediment physico-chemical parameters based on cultural practice of investigated fish ponds in NIFAGOL Farm, Osun State, Nigeria, 2006-2007

Parameter	Pond						ANOVA	
	FNF		FF		NFF		F value	P
	Range	Mean ± S.D.	Range	Mean ± S.D.	Range	Mean ± S.D.		
Sand %	39.00 - 89.00	68.17 ± 20.77	63.00 - 92.00	76.80 ± 9.27	39.00 - 92.00	70.69 ± 14.83	1.175	0.329
Silt %	3.00 – 31.00	14.50 ± 10.91	2.00 – 19.00	11.90 ± 5.86	2.00 – 31.00	13.58 ± 7.64	0.251	0.780
Clay %	8.00 – 36.00	17.33 ± 10.71	6.00 – 21.00	11.30 ± 4.55	6.00 – 36.00	15.73 ± 8.60	2.057	0.154
pH (Water)	6.20 – 7.40	6.88 ± 0.54	6.20 – 7.80	7.10 ± 0.53	6.20 – 7.80	6.96 ± 0.44	0.518	0.604
pH ($CaCl_2$)	5.90 – 7.10	6.53 ± 0.48	6.00 – 7.50	6.87 ± 0.53	5.90 – 7.50	6.67 ± 0.44	1.423	0.264
Hydrogen ion (meq/100g)	0.20 – 0.45	0.33 ± 0.10	0.10 – 0.75	0.32 ± 0.21	0.05 – 0.75	0.33 ± 0.19	0.036	0.964
Aluminium (meq/100g)	0.10 - 0.25	0.18 ± 0.05	0.10 - 0.30	0.20 ± 0.08	0.10 - 0.40	0.20 ± 0.08	0.651	0.532
Sodium (meq/100g)	0.14 – 0.67	0.30 ± 0.20	0.19 – 0.32	0.25 ± 0.05	0.14 – 0.67	0.26 ± 0.10	1.007	0.383
Potassium(meq/100g)	0.13 – 0.46	0.23 ± 0.13	0.12 – 0.49	0.23 ± 0.12	0.08 – 0.49	0.25 ± 0.11	0.671	0.523
Magnesium (meq/100g)	0.08 – 7.00	1.80 ± 2.60	0.03 – 2.56	0.85 ± 1.09	0.03 – 7.00	1.30 ± 1.81	0.686	0.515
Calcium (meq/100g)	4.00 – 7.20	5.30 ± 1.09a	5.20 – 10.00	7.17 ± 1.35b	4.00 – 10.00	5.30 ± 1.09ab	4.830*	0.019
Nitrate (%)	0.01 – 0.13	0.06 ± 0.05	0.01 – 0.11	0.06 ± 0.03	0.01 – 0.23	0.06 ± 0.05	0.004	0.996
Phosphate (ppm)	21.96 – 50.90	34.06 ±10.74a	19.32 – 30.06	26.55 ± 3.45b	19.32 – 55.40	30.67 ± 9.05ab	2.804	0.084
Sulphate (ppm)	21.96 – 78.93	43.26 ± 20.68	22.63 – 140.32	65.02 ± 37.73	21.96 – 149.72	61.25 ± 33.81	0.865	0.436
Organic Matter (%)	0.17 – 2.70	1.18 ± 1.02	0.17 – 2.10	1.11 ± 0.62	0.17 – 4.60	1.13 ± 0.98	0.003	0.997
Organic Carbon (%)	0 .10 – 1.57	0.69 ± 0.59	0.10 – 1.22	0.64 ± 0.36	0.10 – 2.67	0.66 ± 0.57	0.002	0.998
Nickel (mg/100g)	0.09 – 0.59	0.31 ± 0.17	0.02 – 0.53	0.17 ± 0.17	0.02 – 0.59	0.21 ± 0.15	1.582	0.230
Manganese (mg/100g)	2.48 – 11.45	6.97 ± 3.23	4.38 – 17.28	8.74 ± 4.01	2.48 – 17.28	8.11 ± 3.20	0.842	0.446
Lead (mg/100g)	ND – 0.02	0.02 ± 0.00	ND – 0.09	0.09 ± 0.00	ND – 0.24	0.14 ± 0.15	-	-
Copper (mg100g)	0.24 – 1.72	0.89 ± 0.56	0.02 – 1.92	1.03 ± 0.48	0.20 – 2.09	0.99 ± 0.47	0.138	0.872
Arsenic (mg/100g)	0.23 – 0.99	0.72 ± 0.28	0.19 – 0.83	0.47 ± 0.21	0.19 – 0.99	0.59 ± 0.24	1.811	0.189
Iron (mg/100g)	0.44 – 1.33	0.91 ± 0.43	0.46 – 1.40	0.91 ± 0.31	0.44 – 1.73	0.92 ± 0.33	0.048	0.953
Cobalt (mg/100g)	0.01 – 0.20	0.11 ± 0.07	0.07 – 0.22	0.14 ± 0.06	0.01 – 0.32	0.11 ± 0.08	0.665	0.525
Chromium (mg/100g)	0.02 – 0.14	0.07 ± 0.04	0.02 – 0.11	0.05 ± 0.03	0.01 – 0.14	0.06 ± 0.03	1.148	0.337

NB: Values in a row followed by different letters are significantly different ($P \leq 0.05$)
* = Significant
FNF – Fertilized Non flow-through pond
FF – Fertilized flow-through pond
NFF – Not fertilized flow-through pond

Table 4. Seasonal mean values of the sediment physico-chemical parameters based on aquacultural practice of the investigated fish ponds in NIFAGOL Farm, Osun State, Nigeria, 2006-2007

Parameter	Pond									ANOVA	
	FNF			FF			NFF				
	DS	RS	DS / RS	DS	RS	DS / RS	DS	RS	DS / RS	F value	P
Sand %	54.33 ± 21.57	82.00 ± 6.24	0.66	75.00 ± 2.31	78.00 ± 12.13	0.96	72.33 ± 7.57	63.43 ± 16.67	1.14	3.348*	0.056
Silt %	21.67 ± 11.37	7.33 ± 3.79	2.95	14.25 ± 3.40	10.33 ± 6.89	1.38	13.67 ± 5.03	15.14 ± 8.71	0.90	2.073	0.152
Clay %	24.00 ± 12.00	10.67 ± 3.06	2.25	10.75 ± 1.50	11.67 ± 5.96	0.92	14.00 ± 5.29	21.43 ± 9.86	0.65	3.395*	0.054
pH (Water)	6.57 ± 0.55	7.20 ± 0.35	0.91	7.00 ± 0.58	7.17 ± 0.53	0.98	6.87 ± 0.38	6.89 ± 0.28	1.00	0.762	0.480
pH ($CaCl_2$)	6.27 ± 0.47	6.80 ± 0.36	0.92	6.8 ± 0.62	6.92 ± 0.52	0.98	6.47 ± 0.40	6.61 ± 0.25	0.98	0.443	0.648
Hydrogen ion (meq/100g)	0.30 ± 0.10	0.37 ± 0.10	0.82	0.28 ± 0.21	0.35 ± 0.23	0.79	0.18 ± 0.08	0.40 ± 0.23	0.46	0.541	0.590
Aluminium (meq/100g)	0.17 ± 0.06	0.20 ± 0.05	0.83	0.20 ± 0.12	0.19 ± 0.05	1.04	0.28 ± 0.10	0.19 ± 0.09	1.46	2.377	0.119
Sodium (meq/100g)	0.42 ± 0.24	0.18 ± 0.04	2.36	0.25 ± 0.07	0.26 ± 0.04	0.97	0.22 ± 0.06	0.25 ± 0.05	0.86	4.587*	0.023
Potassium(meq/100g)	0.30 ± 0.17	0.16 ± 0.02	1.89	0.29 ± 0.16	0.20 ± 0.08	1.46	0.34 ± 0.01	0.26 ± 0.12	1.31	0.104	0.902
Magnesium (meq/100g)	2.74 ± 3.73	0.85 ± 0.54	3.24	0.09 ± 0.06	1.35 ± 1.18	0.07	1.02 ± 1.17	1.60 ± 2.18	0.64	1.450	0.258
Calcium (meq/100g)	5.60 ± 1.40	5.00 ± 0.87	1.12	7.40 ± 2.00	7.02 ± 0.90	1.05	5.27 ± 0.21	6.45 ± 1.56	0.82	0.761	0.480
Nitrate (%)	0.09 ± 0.06	0.03 ± 0.03	2.65	0.09 ± 0.02	0.04 ± 0.02	2.41	0.06 ± 0.04	0.06 ± 0.07	1.09	0.797	0.464
Phosphate (ppm)	27.29 ± 4.78	40.84 ± 11.31	0.67	23.94 ± 3.97	28.30 ± 1.68	0.85	24.93 ± 2.97	35.44 ± 11.40	0.70	0.937	0.408
Sulphate (ppm)	28.06 ± 5.80	58.47 ± 18.50	0.48	54.26 ± 57.43	72.20 ± 20.70	0.75	65.39 ± 73.03	68.48 ± 14.87	0.95	0.274	0.763
Organic Matter (%)	1.70 ± 1.25	0.66 ± 0.47	2.59	1.70 ± 0.34	0.71 ± 0.40	2.39	1.23 ± 0.76	1.08 ± 1.47	1.14	0.645	0.535
Organic Carbon (%)	0.99 ± 0.73	0.38 ± 0.27	2.57	0.99 ± 0.20	0.41 ± 0.24	2.39	0.72 ± 0.44	0.63 ± 0.85	1.14	0.634	0.541
Nickel (mg/100g)	0.38 ± 0.21	0.24 ± 0.13	1.55	0.30 ± 0.21	0.08 ± 0.07	3.80	0.21 ± 0.04	0.19 ± 0.12	1.10	1.093	0.355
Manganese (mg/100g)	9.26 ± 2.43	4.68 ± 2.10	1.98	10.26 ± 6.32	7.73 ± 1.40	1.33	9.99 ± 2.75	7.46 ± 1.99	1.34	0.223	0.802
Lead (mg/100g)	0.22 ± 0.00			0.09 ± 0.00			0.24 ± 0.00	0.03 ± 0.00	8.00		
Copper (mg/100g)	1.29 ± 0.49	0.49 ± 0.24	2.65	0.94 ± 0.80	1.09 ± 0.12	0.86	0.77 ± 0.52	1.11 ± 0.42	0.70	2.975	0.074
Arsenic (mg/100g)	0.72 ± 0.14	0.72 ± 0.43	0.99	0.54 ± 0.26	0.43 ± 0.18	1.27	0.62 ± 0.25	0.62 ± 0.22	1.00	0.123	0.885
Iron (mg/100g)	1.12 ± 0.37	0.70 ± 0.44	1.59	1.11 ± 0.44	0.78 ± 0.10	1.42	0.89 ± 0.13	0.94 ± 0.37	0.95	0.866	0.436
Cobalt (mg/100g)	0.12 ± 0.04	0.09 ± 0.10	1.33	0.16 ± 0.07	0.12 ± 0.05	1.33	0.09 ± 0.07	0.10 ± 0.11	0.88	0.396	0.678
Chromium (mg/100g)	0.07 ± 0.03	0.07 ± 0.06	0.95	0.03 ± 0.02	0.06 ± 0.03	0.49	0.04 ± 0.02	0.06 ± 0.04	0.63	0.360	0.702

* = Significant
FNF – Fertilized Non flow-through pond
FF – Fertilized flow-through pond
NFF – Not fertilized flow-through pond
DS – Dry Season
RS – Rainy Season

Table 5. Seasonal mean values of the sediment physico-chemical and heavy metal parameters of of the investigated fish ponds in NIFAGOL Farm, Osun State, Nigeria

Parameters	Dry Season	Rainy Season	t-test for Equality of Means	
	(Mean ± SD)	(Mean ± SD)	t	Sig. (2-tailed)
Sand %	68.00 ± 14.43	72.38 ± 15.30	-0.725	0.476
Silt %	16.30 ± 7.21	11.88 ± 7.62	1.469	0.155
Clay %	15.70 ± 8.59	15.75 ± 8.88	-0.014	0.989
pH (Water)	6.83 ± 0.50	7.08 ± 0.39	-1.209	0.238
pH ($CaCl_2$)	6.54 ± 0.52	6.79 ± 0.37	-1.219	0.234
Hydrogen ion (meq/100g)	0.26 ± 0.14	0.39 ± 0.20	-1.665	0.108
Aluminium (meq/100g)	0.22 ± 0.10	0.18 ± 0.05	0.636	0.531
Sodium (meq/100g)	0.29 ± 0.15	0.23 ± 0.05	0.997	0.342
Potassium(meq/100g)	0.30 ± 0.12	0.21 ± 0.09	1.995	0.057
Magnesium (meq/100g)	1.17 ± 2.18	1.46 ± 1.64	-0.289	0.775
Calcium (meq/100g)	6.22 ± 1.68	6.27 ± 1.33	-0.291	0.773
Nitrate (%)	0.08 ± 0.04	0.05 ± 0.05	1.847	0.077
Phosphate (ppm)	25.24 ± 3.80	32.52 ± 8.32	-3.244**	0.004
Sulphate (ppm)	49.74 ± 50.39	67.87 ± 17.79	-1.110	0.292
Organic Matter (%)	1.56 ± 0.75	0.92 ± 1.05	1.824	0.080
Organic Carbon (%)	0.91 ± 0.44	0.53 ± 0.61	1.825	0.080
Nickel (mg/100g)	0.30 ± 0.17	0.16 ± 0.12	2.384*	0.025
Manganese (mg/100g)	9.88 ± 4.06	6.90 ± 2.00	2.405*	0.024
Lead (mg/100g)	0.18 ± 0.08	0.03 ± 0.00	1.630	0.245
Copper (mg/100g)	1.00 ± 0.61	0.99 ± 0.39	0.023	0.982
Arsenic (mg/100g)	0.62 ± 0.22	0.55 ± 0.26	0.493	0.627
Iron (mg/100g)	1.05 ± 0.33	0.82 ± 0.31	1.607	0.121
Cobalt (mg/100g)	0.13 ± 0.06	0.11 ± 0.08	0.688	0.498
Chromium (mg/100g)	0.04 ± 0.03	0.07 ± 0.04	-1.423	0.167

*Significant ($P \leq 0.05$)
**Highly significant ($P \leq 0.01$)

Table 6. Mean values of pond sediment characteristic of the investigated fish ponds in NIFAGOL Farm, Osun State, Nigeria in comparison with the water supplying reservoir and desirable limits

Parameter	Pond			Reservoir's water quality	Desirable limits
	FNF	FF	NFF		
	Mean ± S.D.	Mean ± S.D.	Mean ± S.D.	Mean ± S.D (mg/L)	Persaud et al., 1993 (ppm)
Sand %	68.17 ± 20.77	76.80 ± 9.27	70.69 ± 14.83	NA	
Silt %	14.50 ± 10.91	11.90 ± 5.86	13.58 ± 7.64	NA	
Clay %	17.33 ± 10.71	11.30 ± 4.55	15.73 ± 8.60	NA	
pH (Water)	6.88 ± 0.54	7.10 ± 0.53	6.96 ± 0.44	7.78 ± 0.42	
pH ($CaCl_2$)	6.53 ± 0.48	6.87 ± 0.53	6.67 ± 0.44	NA	
Hydrogen ion (meq/100g)	0.33 ± 0.10	0.32 ± 0.21	0.33 ± 0.19	NA	
Aluminium (meq/100g)	0.18 ± 0.05	0.20 ± 0.08	0.20 ± 0.08	NA	
Sodium (meq/100g)	0.30 ± 0.20	0.25 ± 0.05	0.26 ± 0.10	11.3 ± 1.8	
Potassium(meq/100g)	0.23 ± 0.13	0.23 ± 0.12	0.25 ± 0.11	10.2 ± 2.04	
Magnesium (meq/100g)	1.80 ± 2.60	0.85 ± 1.09	1.30 ± 1.81	1.62 ± 0.80	
Calcium (meq/100g)	5.30 ± 1.09	7.17 ± 1.35	5.30 ± 1.09	16.9 ± 4.4	
Nitrate (%)	0.06 ± 0.05	0.06 ± 0.03	0.06 ± 0.05	0.84 ± 0.10	
Phosphate (ppm)	34.06 ±10.74	26.55 ± 3.45	30.67 ± 9.05	1.18 ± 0.29	600 - 2000
Sulphate (ppm)	43.26 ± 20.68	65.02 ± 37.73	61.25 ± 33.81	15.20 ± 4.03	
Organic Matter (%)	1.18 ± 1.02	1.11 ± 0.62	1.13 ± 0.98	5.20 ± 1.75	
Organic Carbon (%)	0.69 ± 0.59	0.64 ± 0.36	0.66 ± 0.57	3.03 ± 1.02	1 - 10
Nickel (mg/100g)	0.31 ± 0.17	0.17 ± 0.17	0.21 ± 0.15	0.0 ± 0.0	16 – 75
Manganese (mg/100g)	6.97 ± 3.23	8.74 ± 4.01	8.11 ± 3.20	0.038 ± 0.033	460 – 1100
Lead (mg/100g)	0.02 ± 0.00	0.09 ± 0.00	0.14 ± 0.15	0.007 ± 0.019	31 – 250
Copper (mg/100g)	0.89 ± 0.56	1.03 ± 0.48	0.99 ± 0.47	0.005 ± 0.006	16 – 110
Arsenic (mg/100g)	0.72 ± 0.28	0.47 ± 0.21	0.59 ± 0.24	8.29 ± 3.52	6 – 33
Iron (mg/100g)	0.91 ± 0.43	0.91 ± 0.31	0.92 ± 0.33	NA	2 – 4
Cobalt (mg/100g)	0.11 ± 0.07	0.14 ± 0.06	0.11 ± 0.08	NA	50
Chromium (mg/100g)	0.07 ± 0.04	0.05 ± 0.03	0.06 ± 0.03	NA	26 – 110

FNF – Fertilized non flow-through pond
FF – Fertilized flow-through pond
NFF – Not fertilized flow-through pond
NA – Not Assessed

Discussion

Fish ponds are completely man-made environments, with constant additions of fertilizer and feed to increase the culture's productivity and profitability. The impact of management and feeding could cause major issues in fishponds because the majority of food that is not consumed by fish is available for the growth of algae and bacteria. As observed during the current study, a wide range of environmental factors operating in the fish pond system, such as liming, fertilization, feeding with exogenous feeds, aquatic animal feces, dead animals, and higher aquatic vegetation, had a significant impact on sediment characteristics.

These organic waste components darkened the pond sediment hence the colors recorded were generally dark indicating their reduced state (Boyd 1995). The olive yellow coloration in pond 6 could be attributed to low of aquacultural activities observed during the study period, and even the fact that it is flow-through, so a small amount of organic waste sinks to its bed. And since the water is not turbid, the light coloration could also be attributed to sediment transport caused by flow and exposure to direct sunlight. (Berkowitz et al. 2018). According to Aldorfer (1974), the color of sediments, could also be an indicator of the drainage pattern, so the observed sediment coloration of red, yellow and brown color implies good drainage. While the grayish coloration observed in pond 3 in February indicated poor drainage, this was due to the pond being left almost stagnant for a long duration to fallow.

The average percentage clay was 20% which is an optimal state for bottom sediment in properly built ponds to minimize the risk of excessive seepage (Boyd 1995). The variation in textural composition observed during the study period, on the other hand, could be due to pond erosion and sedimentation. Sandy nature recorded, mostly during rainy months, in the ponds could be attributed to their susceptibility to erosion which could have prevented sedimentation of fine particles (silt and clay) and organic waste sink.

Conversely, highest percentage sand was also observed in the flow-through ponds as compared to the non-flow-through ponds. The highest percentage of silt recorded in the non-flow-through ponds further proved the tendency of organic waste to sink faster when the waterbody is stagnant. The accumulation of clay, silt and nutrients in the fertilized pond sediment has been linked to intensive management which may result in in pond depth and space reduction (Rahman et al. 2004). Despite this, only a minimal accumulation of silt and other nutrients was recorded in the fertilized flow-through ponds. Therefore, in order to minimize eutrophication during fish culture, fertilized flow-through production method would be most suitable. This was also confirmed by detection of lowest mean concentration of total phosphate in these set of ponds. Hartono et al. (2019) observed that continuous flow of water over fishpond sediment reduces phosphorus bonding energies, minimizing the rate of phosphorus adsorption by the sediment.

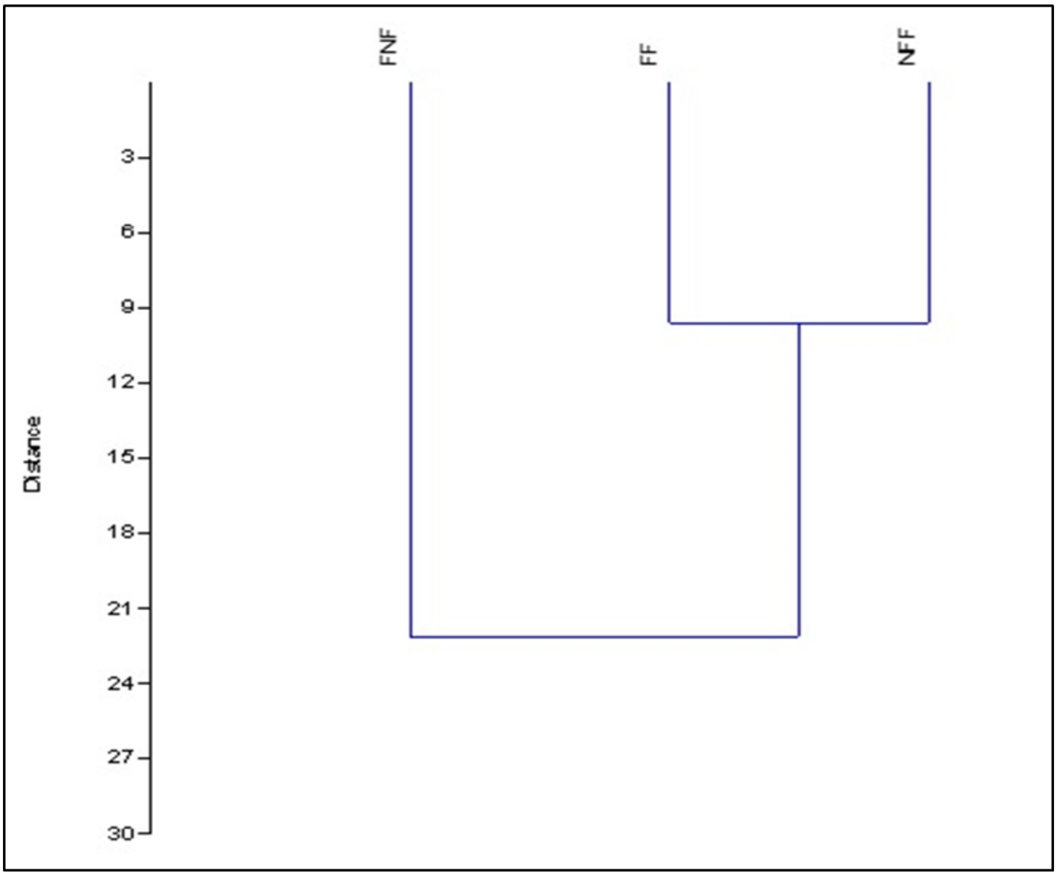

Figure 1. Cluster analysis showing the relationship between fishponds based on the sediment quality parameters studied

The pH of commercial fish farm sediment was on the average below 7.5 which could be attributed to the clayey nature of the sediment (Wurt and Masser 2004). However, the pH range was 6.5 to 7.2, suggesting that the sediments were medium acidic, slightly acidic, or neutral. This acidic condition is a common problem in pond aquaculture and liming of ponds has been the solution (Boyd and Tucker 1998). Acidity and pH of sediment are known to be caused by the exchangeable aluminium and hydrogen ions in the sediment. Therefore, based on the values of exchangeable aluminium ion recorded which ranged from 0.10 meq/g to 0.40 meq/g, the ponds had very low exchangeable acidity. The concentration of exchangeable aluminium ion was high, especially in the flow-through ponds, indicating a higher proportion of basic cations (calcium, magnesium, sodium and potassium). Whereas, the observed increase in hydrogen ion concentrations in the sediment during the rainy season has been attributed to rising in-flow of floodwaters, as well as the subsequent re-cycling and settling of benthos materials (Boyd et al. 2002).

On the average, the pond sediment organic carbon recorded in this study fell within the usual range of 0.5% to 5% organic carbon (Boyd et al. 2002). Occasionally during the study period, the organic carbon in the sediment was less than 0.5 percent, which is very low and will not support good benthos growth. However, the lowest percentage of organic carbon and matter recorded in fertilized flow-through pond may be due to its existing flow and management process. In general, the sediments with mineral soil of low organic matter content are excellent condition for ponds with exogenous feeding.

The calculated carbon: nitrogen ratio ranged from 8.5: 1 to 16.0: 1, implying that these waterbodies might not be susceptible to anaerobic condition at the sediment-water interface (Boyd et al. 2002). Based on the Healey and Hendzel's nitrogen deficiency criterion, (C: N ratio < 9- No deficiency; 9-15 – moderate and >15 – severe) (Gautam and Bhattarai 2008), all the investigated waterbodies were not nitrogen deficient during the study period. However, pond 6 (Non-fertilized flow-through) undergone considerable nitrogen deficiency in April and October 2007, possibly due to the accumulation of stable organic matter that decomposes slowly. The source of these organic matter may be linked to the erosion influx that occurs at these times of year.

The phosphorus concentrations measured in this analysis were within the optimum range of 30-60 ppm (Munsiri et al. 1995). The low sediment phosphorus concentration observed during the rainy season may be attributed to seasonal mixing at the water-sediment interface, which results in the release of sediment phosphorus into the water (Gerhardt et al. 2010). The higher sulphate concentrations observed in flow-through ponds may be linked to erosion, which is the primary source of sulphur in non-acidic sulfate soils (Munsiri et al. 1995). Cation's concentrations of sediments in the present study were far below average range obtained from 358 freshwater fish ponds by Munsiri et al. (1995). Since acidic sediment usually contains little to no calcium carbonate, as seen in ponds located on calcareous soils, the low calcium level in the ponds confirmed the acidity of the sediments (Munsiri et al. 1995). Furthermore, the cationic hierarchy was such that calcium concentration was greater than sodium concentration in all ponds, which was responsible for the lower pH observed. As sodium is a known basic cation whose presence in high concentrations leads to high pH (Munsiri et al. 1995). The sodium adsorption ratios (SAR) as calculated were also quite low and generally below 0.50 which further confirmed the acidity of the sediment (Boyd et al. 2002).

The highest concentration of calcium in the fertilized flow-through ponds is also an advantage this method of production had over others as it connotes availability of notable level of calcium in the ponds. According to the literature, calcium plays an important role in reducing sodium and potassium ion loss from fish body fluid (Wurts and Durborow 1992). It also improves phosphorous availability for primary productivity (Wurts and Masser 2004), allows for the blocking of copper and zinc effects at the site of their toxic activity (Wurts and Perschacher 1994), and sedimentation of muddy water (Wurts 2002). Conversely, the high sodium levels observed in fertilized non-flow-through ponds are most likely due to significant loss of sodium and magnesium salt from the fishes' body fluid into the water (Wurts and Durborow 1992), which then settles into the bottom sediment.

The presence of the micronutrients such as iron, manganese, cobalt, copper and other heavy metals in the sediments have been connected to high pH and alkalinity which favors micro - nutrient precipitation. (Boyd 1995). Flowage, on the other hand, promoted the presence of 5 of the 8 investigated heavy metals, with high concentrations of these metals (Fe, Mn, Cu, Co, and Pb) in the flow-through ponds. The high Pb and Fe concentrations may be attributed to the material of pipe network used to supply water to the ponds. Nonetheless, their concentrations in these sediments, which were very low to low (based on the range developed by Munsiriet al. 1995), may be classified as non-toxic (MacDonald et al. 2000). Furthermore, with the exception of iron in all of the ponds, the majority of the heavy metals were within the suitable range for sediment. (Table 6).

The significant variations in clay, silt and nutrient parameters accumulation (phosphate, organic matter and carbon) based on flowage, as well as the significant availability of calcium ion in the fertilized flow-through ponds, revealed that revealed that this mode of fish culture is probably the most suitable one in the study area. As a result, more research should be done to determine the best water flow rate for the fertilized flow-through ponds.

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