aquaculture journal

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The Effect of Water Quality on Aquaculture Productivity in Ibanda District, Uganda

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Citation: Tumwesigye, Z.; Tumwesigye, W.; Opio, F.; Kemigabo, C; Mujuni, B. The Effect of Water Quality on Aquaculture Productivity in Ibanda District. **2021**, *1*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s):

Received: date
Accepted: date
Published: date

Abstract: Water quality plays a substantial role in maximizing fish productivity. Despite the efforts made by government to improve fish production, there are general complaints about small size of fish produced in aquaculture systems. The study was conducted to assess the effect of water quality on aquaculture productivity in Ibanda District. The specific objectives were to examine the status of water quality parameters (Temperature, Turbidity, pH, Alkalinity, Ammonia, Hardness, Carbon-dioxide and Iron) and assess their effect on fish pond productivity. Using data from fish farmers and water samples taken from 25 restocked fish ponds in 10 sub-counties, the study revealed that out of the eight water quality parameters examined, only four parameters namely; average turbidity, alkalinity, hardness, Carbon-dioxide were within the acceptable ranges while Ammonia, temperature, pH and Iron were slightly outside the recommended ranges. The study also revealed that water quality parameters such as; temperature, pH, Ammonia, Carbon-dioxide and Iron had a significant effect on the weight and size for both tilapia and catfish. The study concluded that some water quality parameters have a detrimental effect on fish farming. There is a need for educating fish farmers on how to maintain water quality at suitable levels in order to improve fish productivity in Ibanda district.

Keywords: Parameters; Temperature; Turbidity; pH; Alkalinity; Ammonia; Hardness; Carbon-dioxide; Iron; Fish pond

1. Introduction

Aquaculture is "the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants [1]. Water quality refers to the chemical, physical, biological and radiological characteristics of water [2]. Water is a critical factor in the life of all aquatic species. Maintaining water quality plays a substantial role in maximizing fisheries productivity [3]. It is essential that different water quality parameters are monitored and kept within the optimum range to sustain growth and survival of fish [4]. In aquaculture, any characteristic of water that affects the survival, reproduction, growth, or management of fish or other aquatic creatures in any way is a water quality variable [5]. In all culture systems, fish performs its physiological activities such as breathing, excretion of wastes, feeding, maintaining salt balance and reproduction in the water medium. Accordingly, the overall performance of any aquaculture system is partly determined by its water quality [6].

Globally, aquaculture has been in existence for millennia but only started to contribute significantly to the global food supply and rural livelihoods about 30 years ago [7]. Whereas aquaculture provided just 7% of fish for human consumption in 1974, this share increased to 26% in 1994 and 39% in 2004 [8]. By 2014, global seafood production had increased to 167 million tones, almost entirely due to the growth of aquaculture, increasing at the rate of 7.7% per annum from 1985–2013 [8]. Total global aquaculture production increased by 4.5 percent from 105.46 million tones (live weight equivalent) in 2015 to a new high of 110.21 million tones in 2016, with total production valued at US$ 243.26 billion [3].

Though there has been a tremendous increase in aquaculture production, poor water quality has been reported to adversely affect global aquaculture production by mainly affecting fish growth, production, quality and profitability [9]. Aquaculture production has been reduced by contaminated waters that impair development, growth, reproduction or even cause mortality to the cultured fish species [10]. As a result, global fish farmers have been obliged to manage water quality so as to provide a relatively stress-free environment that meets the physical, chemical and biological standards for the fish's normal health and growth [11].

In Africa, aquaculture production stands at around 1.74 million tones less than 2% of global production. This is mostly produced in Egypt (*c.* 1.1 million tones) with other major producers being Nigeria (313,000 tones) and Uganda (111,000 tones). Almost half (43.6%) African production is of Nile tilapia [12]. Other freshwater fish species such as African catfish (11.9%) and common carp (10.5%) are also important aquaculture products. Much of the tilapia and catfish are semi-intensively produced, thus requiring additional feeding. There is considerable impetus to develop aquaculture in Sub-Saharan Africa [13]. Lack of information on the basic requirements of an effective aquaculture system by small-scale fish farmers has handicapped the orderly, rapid development and high yield of the aquaculture industry in developing countries [14].

While the Sub-Saharan Africa region has numerous attributes such as underutilized land and water resources, cheap labor, high demand for fish and a favorable climate all year round, aquaculture production is still not at its maximum [15]. Optimal production of fish in aquaculture systems has frequently been curtailed by several factors among them limited information on aquaculture set-up and poor information on pond water quality requirements for optimal fish production [16].

In Uganda, aquaculture is considered as one of the most important sources of animal protein production for meeting the increasing nutritional demand for protein. Uganda produces up to 15,000tones of fish from aquaculture, including production from small-scale fish farmers, emerging commercial fish farmers and stocked community water reservoirs and minor lakes [17]. There are an estimated 20 000 ponds throughout the country with an average surface area of 500 m^2 per fish-pond.

According to the Department of Fisheries [4], there are two key species cultured in Uganda (North African catfish and Nile tilapia) contributing over 90 percent of the total aquaculture production in the country. Because of the shortage of water resources, different sources of water including springs, rain water, drainage and tapped water are usually used in fish farming. These water sources have different physical, chemical and biological characteristics, which have effects on the quality of water and cultured fish [4]. Given that the life and growth of fish in aquaculture systems depend on water quality and feed consumption, successful management of fish ponds therefore requires an understanding of water quality, which is determined by abiotic factors such as temperature, Dissolved Oxygen (DO), transparency, turbidity, water color, carbon dioxide, pH, alkalinity, hardness, unionized ammonia, nitrite, nitrate, primary productivity, plankton population among others [5].

Ibanda District is endowed with numerous permanent streams and swamps and experiences favorable climate which gives its high potential for Aquaculture development. Currently there are about 36 fish farms in Ibanda District with an estimated 86 fish ponds [4]. However, small size of farmed fish produced in Ibanda District has been a major challenge to aquaculture development in the area, demoralizing fish farmers and other intending commercial entrepreneurs [11]. The government of Uganda through agencies like Operation Wealth Creation (OWC) and National Agricultural Advisory Services (NAADs) has made an effort to support fish farming by providing fish fingerlings. However, fish farmers continue to report slow growth and small size of fish stocked [4].

Studies done in other parts of Uganda have linked fish stunted-ness and slow growth to changes in biophysical and chemical properties of water such as temperature, dissolved Oxygen, transparency and turbidity [18]. However, there is limited information on the cause of slow growth and small size of fish stocked under National Agricultural Advisory Services (NAADS) as no study has been done to assess the phenomena in the context of Ibanda District.

Following the dearth in supporting literature, it remains unknown whether there is a significant difference in the status of water quality parameters (temperature, turbidity, pH, Alkalinity, Ammonia, Hardness, Carbon dioxide and Iron levels) from optimal ranges in fish ponds across Ibanda District. Likewise, it remains unknown whether there is a significant effect of the status of water quality parameters (temperature, turbidity, pH, Alkalinity, Ammonia, Hardness, Carbon dioxide and Iron) on Aquaculture productivity (fish weight and size) in Ibanda District.

It is against this background that this study was set out to examine the status and effect of water quality parameters (Temperature, Turbidity, pH, Alkalinity, Ammonia, Hardness, Carbon oxide and Iron levels) on aquaculture productivity in 25 selected aquaculture systems in Ibanda district. Aquaculture productivity was assessed in terms of size.

2. Materials and Methods

2.1. Study Area

The study was conducted across ten sub-counties of Ibanda District including Nyamarebe, Ishongororo, Kijongo, Kikyenkye, Nyabuhikye, Rukiri Keihangara, Bufunda, Bisheshe and Kagongo division (Figure 1). The sub-counties were purposefully selected based on the location of fish ponds stocked in the year 2019 under Production and Marketing Grant (PMG), Agriculture Extension Grant (AEG) and Operation Wealth Creation (OWC) programs, all operating under the Ministry of Agriculture Animal Industry and Fisheries (MAAIF).

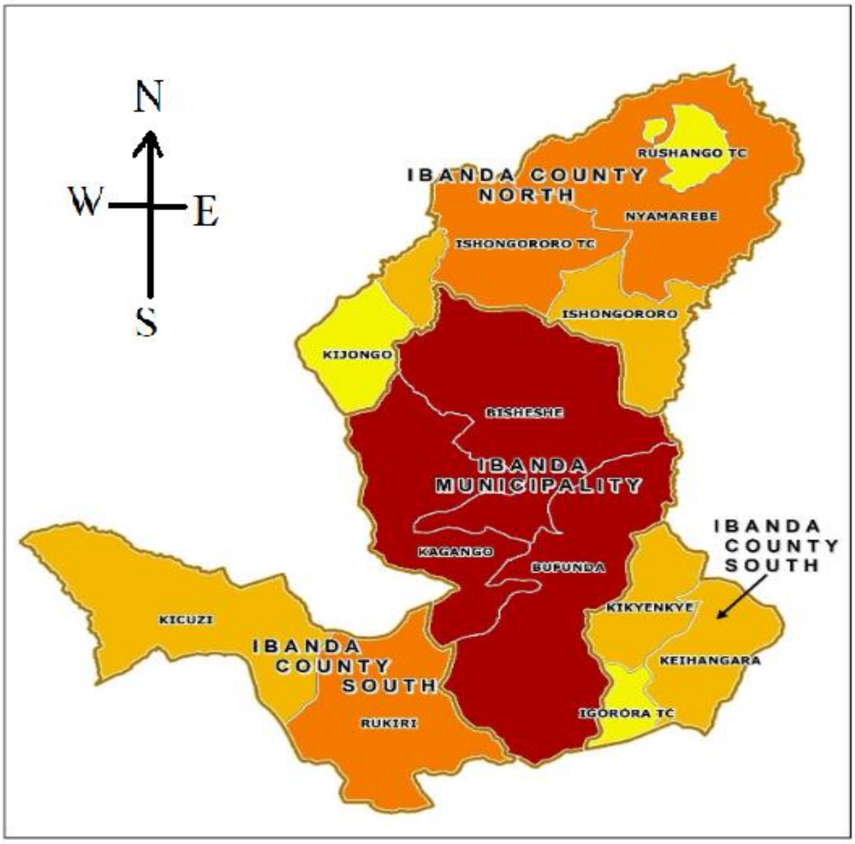

Figure 1: Map of Ibanda District showing the study area
Source: Uganda Bureau of Statistics [33].

2.2. Research Design

A descriptive cross-sectional survey engaging both qualitative and quantitative approaches was used to gather and analyze information from restocked fish ponds and key informants. The quantitative approach enabled exactness and clarity in the measurement of quantifiable information while the qualitative approach enabled extensive and deeper investigation into the phenomena. Data was gathered from twenty-five (25) fish farms that had benefited from a restocking program by agencies under Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) and Production and Marketing Grant (PMG).

2.3. Sampling Techniques

Purposive sampling technique was employed in the selection of all the 25 restocked ponds and farms. Total population sampling is a type of purposive sampling technique where an entire population (i.e., the total population) that has a particular set of characteristics (e.g., specific experience, knowledge, skills, exposure to an event, etc.) is examined. All the 25 fish ponds restocked from 10 sub-counties constituted the sampling frame.

2.4. Data Collection Methods and Instruments

A structured interviewee administered questionnaire was used to gather quantifiable information from ponds and their owners'. Oral interviews using an interview guide were used to capture opinions and views from different key informant categories. An observation checklist in line with study aspects was also used to supplement the gathered data. Water Testing Kit (WTK) and Fish Sampling tool were the main methods used for testing and capturing data on water quality parameters, weight and size of fish.

This was achieved through observations and testing water samples taken from fish ponds. Weight and size of fish was determined using a scooping net to capture more than 10 fish from 4-corners of each pond. Using electronic balance, average fish weight (g) from each pond was determined and a ruler calibrated in (cm) was used to measure average total length of netted fish [19].

Eight(8) water quality parameters were tested namely; Turbidity (Secchi disc depth in cm), Alkalinity (mg/L), Total Hardness (mg/L), Iron (Fe) (mg/L), Carbondioxide (CO_2) (mg/L), Ammonia (NH_3) (mg/L), temperature and water pH. On the other hand, fish productivity was assessed in terms of weight and size of the tilapia and catfish respectively. The relationship was tested at a 5% level of probability. These parameters were determined using analytical methods as described in a Laboratory Manual for the Examination of Water and Waste-Water by National Water and Sewerage Cooperation, Uganda [20].

2.5. Data Analysis

The questionnaire was checked for completeness, coded and entered into Microsoft EXCEL and then exported to Statistical Package for Social Scientists (SPSS), Version 20 for cleaning and analysis. Data were analyzed to generate descriptive and inferential statistics which aided in presentation and interpretation of findings. The generated findings are presented in statistical tables. The mean of each water quality parameter tested was compared with the recommended optimal ranges which were extracted from the literature review as presented below.

Table 1. Optimal range of water quality parameters in aquaculture systems.

S/N	Parameter	Optimal range	stress	Source
1	Temperature (^{0}C)	28-32	<12,>35	[21]
2	Turbidity (cm)	30-80	<12,>80	[22]
3	CO_2 (mg L-1)	5-8	>12	[12]
4	pH	6.5-8.5	<4,>11	[23;24;25]
5	Alkalinity (mg L-1)	75-200	<20,>300	[9]
6	Hardness (mg L-1	30-180	<20,>300	[26]
7	Ammonia (mg L-1	0<0.05	>0.3	[27]
8	Fe (mg L-1)	0.1<0.2	>0.2	[28]

3. Results

This section categorizes results in different sub-sections including demographic characteristics of fish farmers, pond characteristics, type of fish, status of water quality parameters and the effect of water quality parameters on fish productivity.

3.1. Demographic Characteristics of Pond Owners

Table 2. Demographic characteristics of Pond Owners (n=25).

Variable	Values	Frequency	Percentage
Gender	Male	22	88
	Female	3	12
	Min.	**Max.**	**Mean ± SD**
Age in years	25	70	45.57 ±13.359
Educational in years	5	13	10.60 ± 4.284

A total of 25 pond owners responded to the questionnaires indicating their gender. The majority (88%) were male and 12% female. Mean age of the respondents was 45 years with a minimum of 25 and maximum of 70 years. Average years in school were 10 with a minimum of 5 and a maximum of thirteen (13) years.

3.2. Pond Characteristics

Table 3. Pond information.

Variable	Values	Frequency	Percentage
Type of pond	Earthen	22	88.0
	Tank	2	8.0
	Others	1	4.0
	Min.	**Max.**	**Mean ± SD**
Number of ponds owned	1	6	2.72 ± 1.720
Pond size (m^2)	80	1200	450.20 ± 420.585
Pond depth (m)	0.914	2.134	1.756 ± 0.492

As shown in table 3, the majority (88%) of the respondents had earthen ponds, 8% tank ponds and 4% other type of ponds. Average number of ponds owned was 2 with a minimum of one pond and a maximum of six (6). On average, ponds were measuring 450.2m^2 with the smallest pond measuring 80m^2 and the biggest 1200m^2. Average pond depth was 1.756m with the shallowest pond measuring 0.914m deep and the deepest 2.13m.

3.3. Type of Fish Cultured

Table 4. Type of fish cultured, weight at stocking and harvesting (n=25).

Variable	Values	Frequency	Percentage
Type of fish cultured	Tilapia	10	40.0
	Catfish	15	60.0
	Min.	**Max.**	**Mean ± SD**
Weight at stocking(g) for catfish	5	5	5.00 ± .000
Weight at stocking(g) for tilapia	3	3	3.00 ± .000
Weight at harvest(g) for catfish	265.0	567.0	397.740 ± 94.2463
Weight at harvest (g) for tilapia	101.0	183.0	136.550 ± 31.7868

As shown in table 4, 60% of the respondents cultured Catfish and 40% Tilapia. Average weight of fish at stocking was 5 grams for catfish and 3 grams for tilapia respectively. Average weight at harvest after growing for 6months was 397.740 grams for catfish and 136.550 grams for tilapia.

3.4. Status of Water Quality Parameters

Table 5. Mean of physical-chemical parameters of the fish ponds (n=25).

Water parameter	N	Min.	Max.	Mean ± SD
Turbidity (Secchi disc depth in cm)	25	16.0	90.8	52.652 ± 19.4436
Total Alkalinity (mg/L)	25	20	150	81.64 ± 32.569
Total Hardness (mg/L)	25	20	110	66.40 ± 19.765
Iron (Fe) (mg/L)	25	.025	.415	.21516 ± .109258
CO_2 (mg/L)	25	1.00	9.92	5.5116 ± 2.39041
NH_3 (mg/L)	25	.18	2.49	.7916 ± .55085
Temperature (^{0}C)	25	14	29	22.96 ± 4.809
Water pH	25	4.9	7.5	6.148 ± .7304

Results of the analysis for the mean physical-chemical parameters across the 25 fish ponds is presented in table 5. Average turbidity (Secchi disc depth in cm) across the ponds was (52.652 ± 19.4436), alkalinity in mg/L (81.64 ± 32.569), hardness in mg/L (66.40 ± 19.765), Iron in mg/L (0.21516 ± .109258), carbon dioxide in mg/L (5.5116 ± 2.39041), NH_3 in mg/L (0.7916 ± .55085), temperature in °C (22.96 ± 4.809) and water pH (6.148 ± .7304).

3.5. Effect of the Status of Water Quality Parameters on Fish Productivity

The results in table 6 presents a correlation matrix between water quality parameters and fish productivity.

The results presented in table 6 show that Turbidity had a moderate positive significant correlation with catfish weight ($r = .579^{**}$ p=.028) and tilapia size ($r = .553^{*}$ p=.036). A change in turbidity led to a change in catfish weight and tilapia size.

Total alkalinity presented a moderate positive correlation with tilapia size (r =.524* p=.040) and weight (r =.515**p=.046). A change in alkalinity was found to affect tilapia size and weight but had no effect on catfish size and weight.

Water hardness presented a moderate positive significant correlation with tilapia size (r =.449* p=.046) and presented no correlation with weight as well as size and weight of catfish.

Table 6. Correlations matrix of water quality parameters with fish weight and size.

Parameters		Catfish		Tilapia	
		Weight (g)	Size (cm)	Weight (g)	Size (cm)
Turbidity (Secchi disc depth in cm)	Pearson Correlation	.579**	.220	.276	.553*
	Sig. (1-tailed)	.028	.215	.220	.036
	N	15	15	10	10
Total Alkalinity (mg/L)	Pearson Correlation	-.155	-.022	.515	.524*
	Sig. (1-tailed)	.290	.469	.046	.040
	N	15	15	10	10
Total Hardness (mg/L)	Pearson Correlation	-.170	-.024	.377	.449*
	Sig. (1-tailed)	.272	.466	.142	.046
	N	15	15	10	10
Iron (Fe) (mg/L)	Pearson Correlation	-.389	-.336	-.075	-.264
	Sig. (1-tailed)	.049	.110	.419	.230
	N	15	15	10	10
CO_2 (mg/L)	Pearson Correlation	-.150	-.393	-.487	-.343
	Sig. (1-tailed)	.297	.047	.041	.166
	N	15	15	10	10
NH_3 (mg/L)	Pearson Correlation	-.449*	-.493*	.060	-.090
	Sig. (1-tailed)	.047	.031	.435	.402
	N	15	15	10	10
Temperature	Pearson Correlation	.428*	.352	.022	-.126
	Sig. (1-tailed)	.056	.099	.476	.365
	N	15	15	10	10
Water pH	Pearson Correlation	.203	.177	.637*	.430
	Sig. (1-tailed)	.234	.264	.024	.107
	N	15	15	10	10

Iron (Fe) had a negative imperfect significant correlation with catfish weight (r =-.389p=.049). A unit change in Iron (Fe) negatively reduced catfish weight. Iron had no correlation with catfish size and tilapia weight and size.

Carbon dioxide presented a negative moderate significant relationship with catfish size (r =-.393 p=.047) and tilapia weight (r =-.487p=.041). A unit change in Carbon dioxide in the water negatively affected catfish size and tilapia weight. Carbon dioxide however had no correlation with catfish weight and tilapia size.

NH_3 levels had a negative correlation with catfish weight (r =-.449* p=.047) and size (r =-.493* p=.031). A change in NH_3 levels was found to negatively affect catfish weight and size.

Temperature had a positive moderate correlation with catfish weight (r =.428*p=.056). A unit increment in temperature increased catfish weight but had no effect on size (total length).

Water pH had a positive strong correlation with tilapia weight (r =.637* p=.024). A change in water PH caused a change in tilapia weight but had no effect on tilapia size.

Table 7. Regression output for water quality parameters effects on weight for both tilapia and catfish.

		WEIGHT				SIZE			
		Tilapia		Catfish		Tilapia		Catfish	
Model	**Variables**	Coeff	Sig.	Coeff	Sig.	Coeff	Sig.	Coeff	Sig.
1	(Constant)	59.656	.000	462.105	.151	15.478	.034	36.389	.048
	Turbidity (Secchi disc depth in cm)	.632	.595	.148	.929	.026	.514	-.002	.980
	Total Alkalinity (mg/L)	.281	.721	-.805	.371	.016	.563	-.050	.295
	Total Hardness (mg/L)	-.940	.690	.111	.927	-.009	.899	.028	.658
	Iron (Fe) (mg/L)	-41.217	.867	-285.433	.018	-1.292	.871	-11.147	.011
	CO_2 (mg/L)	-4.386	.038	-7.704	.039	-.029	.959	-.923	.048
	NH_3 (mg/L)	1.685	.978	-91.016	.017	-.069	.972	-5.021	.017
	Temperature	-4.801	.474	16.545	.028	-.159	.465	.746	.044
	Water pH	34.613	.003	-31.573	.588	.969	.045	-.957	.752
	Sample size	10		15		10		15	
	F value	4.781	.019[a]	3.247	.034[a]	4.959	.035[a]	3.317	.037[a]
	R	0.928		0.901		.941[a]		.903[a]	
	R^2	.862		.812		.885		.816	
	Adjusted R	-.242		.562		-.037		.570	

a. Dependent Variable: Weight (g) at harvest

3.5.1 Effect of Water Quality Parameters on Weight

The F values of 4.781 and 3.247 for tilapia and catfish respectively were significant at 5% for both models indicating that there was a significant linear relationship between weight and all the independent variables (water quality parameters) for tilapia and catfish in the study ponds respectively. Variables like Iron, carbon dioxide, Ammonia, temperature and water pH were significant at various levels. The estimated coefficients for Iron, carbon dioxide, temperature and water pH were negative portraying a negative effect on the weight for both tilapia and catfish. The study revealed that a unit change in the levels of any of these parameters in the pond led to a negative change in dependent variables.

Iron levels, carbon dioxide levels had a negative and a significant effect on catfish weight at a 5% level of significance. An indication that an increase in water Iron in the pond reduced catfish weight by 285g at harvest.

Similarly, carbon dioxide and Ammonia levels had a negative but significant effect on the weight for both tilapia and catfish at 5% significance level. The model predicted that a unit increase in Carbon dioxide in mg/L decreased fish weight at harvest by 4.4g and 7.7g for tilapia and catfish respectively. A unit increase in ammonia levels (in mg/L) reduced cat fish weight at harvest by 91g.

Temperature and Water pH had a positive effect on catfish weight at harvest at a 5% level of significance. A unit increase in water temperature increased catfish weight 16.5g at harvest. Likewise, a unit increase in water pH was found to increase tilapia weight by at harvest 34.6g.

3.5.2 Effect of Water Quality Parameters on sIze

Regression output for fish size as a result of different water quality parameters is presented in table 7. Of the eight water quality parameters hypothesized, only five came out significant and these included; Iron, CO_2, NH_3, temperature and water pH.

The R^2 of .885 and .816 revealed that all the parameters included in the model explained for 88% and 81% variation in the size for both tilapia and catfish respectively. The F values of 4.959 and 3.317 for tilapia and catfish were significant at 5% for both models.

Iron levels, carbon dioxide levels and ammonia levels (mg/L) had a negative effect on catfish size at a 5% level of significance. A unit increase in Iron levels in mg/L reduced catfish size by 11.1cm while a unit increase in carbon dioxide levels in mg/L reduced catfish size at harvest by .923cm. Likewise, a unit increment in ammonia levels in water reduced catfish size by 5cm at harvest.

Water temperature and water pH had a positive significant effect on catfish size at a 5% level of significance. A unit increase in temperature 1°C increased catfish size by .746cm at harvest. Likewise, a unit increase in water pH reduced tilapia size at harvest by .969 cm.

4. Discussion of Findings

The mean pond water turbidity observed in this study was slightly above the optimal ranges for fish farming of 30-40cm recommended by the World Fish Center [7]. However, the turbidity was within acceptable ranges of 30-60cm and 30-80cm recommended by MAAIF Department Fisheries Resources [4] and Emokaro *et al.*, [22] respectively. The researcher observed that there was high plankton growth and suspended clay particles in the fish ponds as evidenced by the greenish and milky color of the pond water respectively and this might have contributed to the pond water turbidity.

The mean alkalinity observed in this study was in agreement with the findings of Kirya [9], who reported that alkalinity of 75-200 mg/l was suitable for production of Tilapia and catfish in earthen ponds (table 1). The alkalinity values in the study area were above 20mg/l reported to support pond productivity by Mbugua [29] and Mwesigwa [11]. The slightly high alkalinity values are attributed to the calcium carbonate rich under lying rocks whose spring water is the main source of water for fish ponds in Ibanda District. This alkalinity implies an adequate water pH buffering capacity thus minimizing pH fluctuations.

Average water hardness observed across all the ponds studied was under the normal range of 30-180 mg/1 (table 1). The findings are in line with Kirya [9] who recommended total hardness of at least 20mg/1 with the range of above 20mg/ and 30-180 mg/1 as optimal for culturing fish.

Mean pond water CO_2 concentration in this study was within the acceptable range of 5-8mg/l recommended by Mbugua [29]. It is also in agreement with observations of Swann [30], who reported that tropical fish can tolerate CO_2 concentrations of 10 mg/1 provided DO concentrations are above 5mg/l. Carbon oxide ($C0_2$) concentration of 5 - 8mg/l were recommended as essential for plankton photosynthesis while 12 – 15mg/l and above 50mg/1 were sub-lethal and lethal to fishes respectively.

At the same time, the mean un-ionized ammonia among fish ponds in this study was more than the optimal range of 0.02–0.05 mg/l recommended for fish growth [12,27,29]. The concentration of ammonia was higher than 0.6mg/l reported to kill fish at short exposure with damage to gill and kidney cells upon chronic exposure [10]. According to Kausar & Salim, 2017, 0.1 to 0.3 mg/1 are sub-lethal while 0.6 -2.0 mg/1 are lethal. According to MAAIF [27], the maximum limit of ammonia concentration for aquatic organisms was reported to be 0.1 mg/l. However, 0.2 mg/1 total un-ionised ammonia was reported as acceptable and un-ionized ammonia of less than 0.05 mg/l as safe for many tropical fish species [27]. The high concentration of ammonia in this study could be associated with over feeding of the fish, irregular de-silting of ponds and nutrient enrichment from agricultural fields (runoff)

Average water temperature observed in this study was below the acceptable range of 28 - 32^{o}C (table 1) as favorable for tropical fishes such as tilapia and African catfish which are commonly cultured fish species in Uganda [21]. The average water temperature recorded in this study was also below the normal range of 30 - 35^{0}C urged to be tolerable to fish [31]. The low temperature observed in this study was attributed to the cool climate in Ibanda District due to high altitude (1800m above sea level) of the District characterized by mountainous terrain and numerous swamps.

Average water pH observed across ponds in the study area was slightly below the recommended acceptable range of 6.5 to 8.5 (table 1) as suggested by Riche & Garling [16]. However, this result was in line with Boyd [32] who reported the acceptable range for most fish to be from pH 6 to pH 9. Based on the observed alkalinity (81.64 ± 32.569), the fluctuations' in water pH are expected to be minimal thus supportive to fish growth. Water pH could be raised using agricultural limestone though it is an extra economic cost on the fish farmer.

The status of water quality parameters examined could have been influenced by general agricultural practices in the water shed and specific farmer pond management practices such as the type and amount of feed used, fertilizer applied and pond water replenishment frequency.

Regression results using multiple regression model revealed that all the water quality parameters examined had different effects on fish weight and size across the fish pond systems in the study area. For example, Iron levels had a negative but significant effect on catfish weight and size at a 5% level of significance. This implied that an increase in water Iron reduced catfish weight and size by 285g and 11.1cm respectively. It should be noted that fish may suffer from Iron compounds in poorly oxygenated water with low pH where the Iron is present mostly in the form of soluble compounds. Because the surface of the fish gills tends to be alkaline, soluble bivalent Iron can be oxidized to insoluble ferric compounds which cover gills lamellar and hinder respiration. Hindering respiration may affect growth especially for tilapia. This finding is comparable to findings by Riche & Garling [16] who found that at a low temperature of the water and in the presence of Iron, Iron-depositing bacteria multiply rapidly at the gills and further oxidize

Iron compounds. Their filamentous colonies covering gills are generally colorless, but the residue of Iron could give them brown color.

Carbon dioxide levels presented a negative but significant effect on the weight of both tilapia and catfish at 5% significance level. A unit change in carbon dioxide was predicated to decrease weight by 4.3g and 7.7g for tilapia and catfish at harvest respectively. Carbon dioxide further presented a negative but significant effect on catfish size where by a unit increase in carbon dioxide levels reduced catfish size by 0.923cm. This finding is comparable to findings of Emokaro et al., [22] who stated that carbon dioxide rarely causes direct toxicity to fish. Fish may suffocate when CO_2 levels are high and appear unaffected when CO_2 is low.

Ammonia presented a negative but significant effect on catfish weight and size at a 5% level of significance. This implied that a unit increase in ammonia levels of the pond led to a reduction in catfish weight and size by 91g and 5cm respectively. Too much ammonia causes serious problems in pond management. Ammonia in the range of > 0.1 mg/l tends to cause gill damage in fish, destroy mucous producing membranes, and cause sub-lethal effects like reduced growth, poor feed conversion, and reduced disease resistance. Fish suffering from ammonia toxicity typically stop eating and become lethargic. Several causes noticed to increase total ammonia levels in ponds include; overfeeding fish, uneaten food sinks to the bottom, decays and releases ammonia, increasing the load on the nitrifying bacteria in the pond and filter. The study findings are in agreement with Mbugua [29] who indicated that ammonia is the primary excretory product of fishes, but if it is present in high concentrations, it will slow growth rate.

Water temperature was found to have a positive significant effect on catfish weight and size at a 5% level of significance. This implied that a unit increase in temperature (1°C) increased catfish weight by 16.5g and size by 0.746cm. Average temperature across the study ponds was 22.96 °C which was below most ponds' temperature found in the tropical environment. The low temperature in Ibanda District ponds is due to the numerous swamps and mountainous nature of most parts of the study area. The metabolic rate of fish is closely related to the water temperature. The study findings contradict with findings by Mbugua [29] who asserted that the higher the water temperature, the greater the metabolic rate. In a natural habitat, fish can easily tolerate the seasonal changes in temperature that decreases in winter towards 0°C and increases in summer to 20-30°C. In a pond, bottom water temperature remains slightly lower than the surface water temperature which affects feeding and growth.

Lastly water pH presented a positive significant effect on tilapia weight and size at 5% significance level. A unit increase in water pH affected tilapia weight by 34.6g and size by 0.969cm respectively. Fish have an average blood pH of 7.4, so pond water with a pH close to this optimum. An acceptable range would be 6.5 to 9.0. Fish can become stressed in water with a pH ranging from 4.0 to 6.5 and 9.0 to 11.0. Fish growth is limited in water pH less than 6.5, and reproduction ceases and fry can die at pH less than 5.0. Pond water pH fluctuates throughout the day due to photosynthesis and respiration by plants and vertebrates. Typically, pH is highest at dusk and lowest at dawn. This is because night time respiration increases carbon dioxide concentrations that interact with water producing carbonic acid and lowering pH. This can limit the ability of fish blood to carry oxygen. This study findings are in line with Gan et al., [23] who revealed that the drastic fluctuation of pH would cause stress to culture organisms. Normally, it should be maintained at daily fluctuation within a range of 0.4 differences. Control of pH is essential for minimizing ammonia and H_2S toxicity in the culture systems. Extremely high or low pH values cause damage to fish tissues, especially the gills.

5. Conclusions

Based on the findings, the study made the following conclusions;

The mean values for water quality parameters (turbidity 52.652 ± 19.4436, alkalinity 81.64 ± 32.569, carbon dioxide 5.5116 ± 2.39041, water pH 6.148 ± .7304) and hardness 66.40 ± 19.765) across fish ponds in Ibanda District were within the acceptable range for fish growth. However, the concentration of Iron (0.21516 ± 0.109258) and NH_3 (0.7916 ± 0.55085) were higher while water temperature (22.96 °C) was lower than the recommended ranges.

The status of Iron, ammonia and carbon dioxide significantly suppressed increase in catfish weight, while turbidity and temperature significantly supported increase in catfish weight. Also the status of Iron, carbon dioxide and ammonia significantly reduced total length of catfish while temperature significantly supported increase in the total length of catfish.

The status of carbon dioxide significantly suppressed increase in tilapia weight. On the other hand, the status of alkalinity and pH significantly supported increase in tilapia weight, also turbidity, alkalinity, hardness and pH supported increase in tilapia total length.

Increment in water Iron reduced catfish weight and size but had no harm on tilapia. High carbon dioxide levels reduced catfish body weight and size as well as the body weight of tilapia but had no effect on its body size. Increase in Ammonia levels reduced catfish body weight and size but had no effect on tilapia. A rise in water pH increased tilapia body weight and size but had no effect on catfish. Increase in water temperature positively supported increase in catfish body weight and size but had no significant effect on tilapia.

6. Recommendations

The study recommended that the unsuitable water quality parameters especially Iron, ammonia carbon dioxide and pH may require modification.

In order to improve productivity of catfish in aquaculture systems in Ibanda District there is a need to reduce Iron, ammonia and carbon dioxide levels in water

To remove Iron, simply aerate or spray water into the air using water pumps' pressure. Hold water in a settling basin, followed by a slow rate sand filter of about two gallons per square foot per minute. Also, aerated water may be passed over coarse contact media like stones in a multilevel tray.

The media soon becomes coated with Iron hydroxide which promotes catalytic precipitation of Iron from water. Iron can also be removed from water using oxidation by Potassium Permanganate (KMO_4)

followed by filtration. This method can remove 100% Iron from water and all the Iron residues will sit at the bottom of the tank.

Practices such as regular water change out, de-silting, stocking at reasonable density, optimal fertilization and using good feeding practices that maximize the proportion of the feed consumed by fish can reduce ammonia. Also adding a source of organic matter such as chopped hay or dry grass to intensive fish ponds can reduce NH_3 concentration. Adding organic matter with a high concentration of carbon relative to nitrogen promotes the fixation or immobilization of the ammonia dissolved in water. Incorporating ammonia with bacterial cells packages the nitrogen into a particulate form that is not toxic to fish.

To improve performance of Tilapia, there is a need to reduce carbon dioxide concentration in water and raise the pH through application of agricultural lime. Lime can be applied to ponds during crises with low dissolved oxygen to remove carbon dioxide and allow fish to use the existing dissolved oxygen more efficiently

Acidic pond water can be treated with pH Adjuster to raise the pH level. Also water change out is recommended if pH is particularly very low. For ponds with fish, support them with a treatment of Stress Away and Pond Guardian Salt to alleviate the stress factor of poor water quality.

With low mean temperature of 22.9 ^{0}C in Ibanda District, the research recommends introduction of Carps which is an aquaculture fish species that performs well in areas with low temperature.

Extension staff should conduct regular surveillance and monitoring of changes in such parameters so as to recommend appropriate actions to be taken and advise when water modifications may be highly required.

Fisheries Department should set up demonstrations to support hands-on training of fish farmers in practices that improve water quality in aquaculture systems.

7. Areas for Further Research

The study was limited to water quality parameters (Temperature, Turbidity, pH, Alkalinity, Ammonia, Hardness, Carbon-dioxide and Iron). However, there are other factors that affect aquaculture production beyond the parameters studied in this study. Further research should be conducted on the effects of other factors such as; feeding, pond depth, pond shore conditions, pressure and water movements on aquaculture productivity within ponds in Ibanda district.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1.

Author Contributions: Conceptualization, T.Z.; methodology, T.Z.; software, T.Z.; formal analysis, T.Z.; investigation, T.Z.; resources, T.Z.; data curation, T.Z.; writing—original draft preparation, T.Z.; writing—review and editing, C.K. and M.B. visualization, T.Z and M.B.; supervision, T.W and O.F.; funding acquisition, T.Z. All authors have read and agreed to the published version of the manuscript.

Funding: Please add: This research received no external funding

Informed Consent Statement: “Informed consent was obtained from all subjects involved in the study.”

Acknowledgments: I wish to recognize the role played by the entire staff and administration of Bishop Stuart University, the lecturers and all my colleagues in this course who assisted me in one way or the other to achieve the completion of this project. My special thanks also go to my supervisors, Mr. Tumwesigye Wycliffe and Prof. Fina Opio for the time, criticisms, guidance and patience in supervising and correcting every error in this research work to ensure it is up to this standard. In a special way, I want to thank my entire family, siblings, and friends and loved ones for their encouragement, support and ideas towards this Research. Above all, I thank the Almighty God whose grace and mercy guided me all through in this endeavor.

Conflicts of Interest: The authors declare no conflict of interest.

7. References

1. Hyuha, T. S., Bukenya, J. O., Twinamasiko, J., & Molnar, J. Profitability analysis of small scale aquaculture enterprises in Central Uganda. *International Journal of Fisheries and Aquaculture,* **2011**, *3*(15), 271-278.
2. Eruola, A. O., Ufoegbune, G. C., Awomeso, J. A., & Abhulimen, S. A. Assessment of cadmium, lead and iron in hand dug wells of Ilaro and Aiyetoro, Ogun State, South-Western Nigeria. *Research Journal of Chemical Sciences*, **2011**.
3. FAO. *State of Fisheries and Aquaculture in the world 2018.* Rome: Food and Agricultural Organization of United Nations, 2018
4. MAAIF. Essentials of Aquaculture Production, Management and Development in Uganda, 2018
5. MAAIF. Training Manual for Aquaculture Extension Service Providers, 2016
6. Abd El-Hamed, N. *Environmental studies of water quality and it's Effect on fish of some farms in Sharkia and Kafr.* El-Sheikh Governorate: Institute of Environmental studies & Research Ain Shams University, 2014.
7. World Fish Centre. Barriers to Aquaculture Development as a Pathway to Poverty Alleviation and Food Security. *Presentation by M. Beveridge, M. Phillips, P. Dugan and R. Brummett to the OECD Work-shop, Paris, 12–16 April 2010.* World Fish Centre, 2010
8. FAO. *The State of World Fisheries and Aquaculture 2016. Contributing to Food Security and Nutri-tion For All.* Rome: Food and Agricultural Organization of United Nations. Retrieved from http://www.fao.org/3/a-i5555e.pdf, 2016
9. Kirya, D. *Land use change and health: A case study of fish farming impacts on malaria prevalence in Kabale district, Uganda.* Kampala: Un published thesis Lund University, 2011.
10. Umesh, N. R., Mohan, C. V., Phillips, M. J., Bhat, B. V., Babu, G. R., Mohan, A. C., & Padiyar, P. A. *Risk analysis in aquaculture–experiences from small-scale shrimp farmers of India. Understanding and applying risk analysis in aquaculture,* 2008.
11. Mwesigwa, R. M. Economic analysis of commercial aquaculture in central Uganda. Unpublished thesis. Kampala: School of Graduate Studies, Makerere University, 2008.
12. Kausar, R., & Salim, M. Effect of water temperature on the growth performance and feed conver-sion ratio of Labeo rohita. *Pakistan Veterinary Journal,* **2017**, *26*(3), 105-108.
13. Machena, C. & Moehl, J. African Aquaculture: A Regional Summary with Emphasis on Sub-Saharan Af-rica, 2001
14. Davis, J. Aquaculture Development Strategy for Botswana. ACP Fish II Coordination Unit Service Con-tract n° CU/PE1/MZ/10/004, 2011
15. FAO. Fisheries and Aquaculture Department. 2011. Available at http://www.fao. org/fishery/ cultured species/Oreochromis_ niloticus/en, 2011.
16. Riche, M., & Garling, D. F. *Feed and Nutrition. Feeding Tilapia in Intensive Recirculating Systems.* Retrieved May 13, 2017, from http://www.hatcheryfeed.com/hf-articles/141/, 2017
17. National Development Plan. *The Republic of Uganda.* Retrieved August 3, 2012, from http://npa.ug/docs/NDP2.pdf, 2010
18. NaFIRRI. Site suitability and diurnal studies for establishment of appropriate cage designs for use in the Mwena Kalangala Cage Aquaculture Park, 2018
19. Imam, T. S., Bala, U., Balarabe, M. L., & Oyeyi, T. I. Length-weight relationship and condition factor of four fish species from Wasai Reservoir in Kano, Nigeria. African Journal of General Agriculture, **2010**, 6(3), 125-130
20. Adongo F.G. Laboratory Manual for the Examination of Water and Waste-Water: NWSC-CL/QR/09, 2009

21. Finegold, C. *The importance of fisheries and aquaculture to development.* The Royal Swedish Academy of Agriculture and Forestry, 2009
22. Emokaro, C. O., Ekunwe, P. A., & Achille, A. Profitability and viability of catfish farming in Kogi State, Nigeria. *Research Journal of Agriculture and Biological Sciences,* **2010**, *6*(3), 215-219.
23. Gan, L., Liu, Y. J., Tian, L. X., Yue, Y. R., Yang, H. J., Liu, F. J., & Liang, G. Y. *Effects of dissolved oxygen and dietary lysine levels on growth performance, feed conversion ratio and body composition of grass carp, C tenopharyngodon.* 2013.
24. Ahmed, A. A. Inhibition of the Development of micro Algae by Extracts of freshwater Algae. Fac. Sci., Banha Univ., 2012.
25. Abumourad, I. M., Authman, M. M., & Abbas, W. T. Heavy metal pollution and metallothionein expression: a survey on Egyptian tilapia farms. *Journal of Applied Sciences Research,* **2013**, *9*(1), 612-619.
26. Santhosh, B., & Singh, N. *Guidelines for water quality management for fish culture in Tripura.* ICAR Research Complex for NEH Region, Tripura Center, 2007
27. MAAIF Statistical Abstract. *Ministry of agricultural animal industry and fisheries. Agricultural planning department.* Retrieved March 1, 2012, from http://www.agriculture.go.ug/userfiles/Statistical%20Abstract%202011.pdf, 2011.
28. Svobodova, Z., Lloyd, R., Machova, J., & Vykusova, B. *Water quality and fish health. EIFAC Tech-nical Paper.* Rome: Food and Agricultural Organization of the United Nations, 1993
29. Mbugua, H. M. *A Comparative Economic Evaluation of Farming of three Important Aquaculture Species in Kenya.* Reykjavik, Iceland: The United Nations University, 2007
30. Swann, L. *A fish farmer's guide to understanding water quality. Fact Sheet AS-503. Aquaculture Extention, Illinois-Indiana Sea Grant Program.* West Lafayerre, IN., USA: Purdue University, 1997
31. Delince, G. *The Ecology of the Fish Pond Ecosystem.* The Nether-lands: Kluwer Academic Publishers, 1992
32. Boyd, C.E. Water quality in warm water fish ponds. Craftmaster Auburn, Alabama, USA, Printers, 1979Inc.
33. Uganda Bureau of Statistics. The National Population and Housing Census 2014 – Area Specific Profile Series, Kampala, Uganda, 2017