

Influence of Water Quality on Growth Dynamics of Nile Tilapia (*Oreochromis niloticus*) in Uasin Gishu Aquaculture Systems

 Kosgei J. Patricia*,  Liti M. David,  Mutai K. Edwin and  Chemoiwa J. Emily

Department of Biological Sciences, School of Science, University of Eldoret, Eldoret, P.O. Box 1125-30100, Eldoret, Kenya

Abstract

Aquaculture in Uasin Gishu County, Kenya, supports food security and livelihoods but faces challenges from unstable water quality affecting Nile tilapia (*Oreochromis niloticus*) growth. This study examined the relationship between water quality and fish growth across five farms representing earthen, tank, and raised liner systems from May 2023 to April 2024. Physico-chemical parameters—dissolved oxygen (DO), temperature, pH, chemical oxygen demand (COD), and biological oxygen demand (BOD)—were measured at three-hour intervals, while fish growth was monitored monthly. Data were analyzed using ANOVA, Tukey's HSD, and multiple regression to assess water quality effects on growth. Temperature (21–23 °C) was below the optimal 25–30 °C range; pH (8–9) was acceptable; DO occasionally dropped below 3 mg/L; and COD (32–95 mg/L) and BOD (33–103 mg/L) indicated organic loading. Significant differences occurred among farms for temperature, DO, COD, and BOD. Growth parameters derived from the von Bertalanffy Growth Function showed the best performance in raised liner systems, with Cheplaski Farm A recording the highest growth ($L_{\infty} = 36.78$ cm; $W_{\infty} = 630.02$ g). COD and BOD were the strongest predictors of maximum growth rate. The findings emphasize the need for stable water quality management to enhance *O. niloticus* productivity and ensure sustainable aquaculture in the region.

Keywords: Aquaculture, *Oreochromis niloticus*, culture systems, regression analysis, Uasin Gishu County, Von Bertalanffy

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Correspondence: taruspatria@gmail.com

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Introduction

Aquaculture is one of the fastest-growing food production sectors globally, making significant contributions to food security, employment, and rural development (Sanon et al., 2021). Among the more than 400 farmed fish species, Nile tilapia (*Oreochromis niloticus*) is one of the most important, ranked second only to carps in global aquaculture production (Tadesse & Yimer, 2022). Its adaptability to diverse environments, rapid growth, tolerance to stress, and ability to reproduce under confined conditions have made it a preferred species for both smallholder and large-scale aquaculture enterprises (Adeleke et al., 2020). These attributes, coupled with strong consumer acceptance, have earned tilapia the reputation of being the “aquatic chicken” of global aquaculture (Azaza et al., 2020). In Kenya, aquaculture has gained prominence as a key contributor to food and nutrition security, poverty alleviation, and economic development (Munguti et al., 2024). The sector experienced limited growth until the introduction of the Economic Stimulus Programme (2009–2013), which supported pond construction, provision of quality fingerlings, and input subsidies (Opiyo et al., 2023). These interventions, alongside advances in research and extension, raised annual aquaculture production from less than 1,000 tonnes in the early 2000s to over 18,000 tonnes by 2020 (FAO, 2022). Despite this progress, productivity in many farms remains constrained by environmental challenges,

particularly unstable water quality and poor facility management.

Water quality is a fundamental determinant of aquaculture success, as it directly influences fish survival, health, and growth performance (Odende et al., 2022). Key physico-chemical parameters such as dissolved oxygen (DO), temperature, pH, chemical oxygen demand (COD), and biological oxygen demand (BOD) regulate the physiological functioning of fish and the ecological balance of culture systems. Suboptimal levels of these parameters can impair metabolism, reduce growth, and increase disease susceptibility, ultimately lowering farm profitability. In Kenya, inadequate monitoring and poor management practices, such as overstocking and irregular water exchange aggravate fluctuations in water quality, posing risks to aquaculture sustainability (Sallam et al., 2025).

Against this backdrop, it is necessary to investigate the relationship between water quality and growth performance of *O. niloticus* in different aquaculture systems. Uasin Gishu County provides a relevant case study due to its diverse aquaculture facilities, including earthen ponds, tanks, and liner-based systems, which reflect the production practices of smallholder and emerging commercial farmers. Understanding how variations in water quality influence tilapia growth across these systems will provide insights to guide management interventions, strengthen aquaculture

productivity, and promote sustainability in the region.

Materials and Methods

Study sites

The study was conducted across five selected fish farms in Uasin Gishu County, Kenya, from May 2023 to April 2024 (Figure 1). Within the Great Rift Valley region, Uasin Gishu County lies

approximately 330 Km Northwest of Nairobi along the Kenya-Uganda highway. It shares borders with Trans-Nzoia County to the North, Elgeyo-Marakwet and Baringo counties to the East, Kericho County to the South, Nandi County to the southwest, and Kakamega County to the West. Covering an area of 2,955 km², the county's geographical coordinates range between Longitude 34°50" E and 35°37" W, and Latitude 0°03" S and 0°55" N.

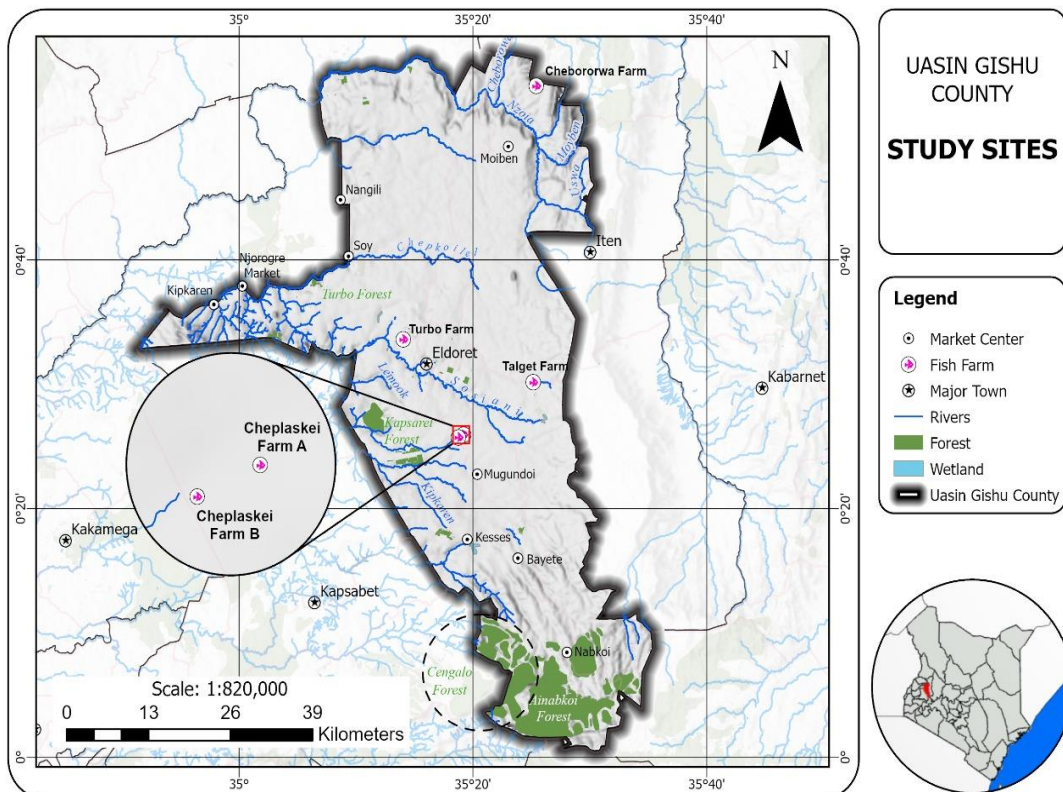


Figure 1. Study area showing the spatial distribution, geographic coordinates, and elevations of the five sampled fish farms in Uasin Gishu County

Selection of the Study Sites

The locations were selected for the study because they were good representative of the area based on the interest of the study, the information to be collected, and accessibility. A stratified random sampling procedure was employed to select 5 farms from which water and fish samples were collected. Operational aquaculture farms from each of the four sub counties were selected

based on; the type, size and the location of the aquaculture facility, aquaculture facility inputs (fish feeds), and number of year(s) of operation (minimum 1 year).

Description of Study Sites

The study was undertaken across five fish farms located in different sub-counties of Uasin Gishu County, each with varying aquaculture systems, sizes, and levels of activity. Together, these sites provided a diverse representation of

production environments within the study area.

Chebororwa Farm, situated in Moiben Sub-County, had a total of seven aquaculture facilities. However, only four of these were actively in use for fish farming during the study period and were lined with polythene, covering an area of approximately 60 m² and three earthen ponds, each measuring approximately 300 m². Talget Farm, located in Ainabkoi Sub-County, comprised three aquaculture facilities consisting of two liner ponds and one earthen pond, with each facility covering an area of about 300 m².

In Kesses Sub-County, two farms were studied. Cheplaskei Farm A consisted of two tanks constructed with wooden frames and lined with polythene, each measuring approximately 50 m², while Cheplaskei Farm B comprised two earthen ponds, each with an area of 300 m². The final site, Turbo Farm, was located in Turbo Sub-County and had two liner ponds, each measuring 300 m².

Overall, the five farms represented a combination of earthen ponds, liner ponds, and tanks, with sizes

ranging from small-scale tanks of 50 m² to larger earthen and liner ponds of 300 m². This diversity of aquaculture systems provided an opportunity to evaluate water quality and fish growth performance under different culture environments across Uasin Gishu County.

Research design

The study employed a longitudinal research design, which involved monitoring of both physicochemical water quality parameters and fish growth performance over a twelve-month period, from May 2023 to April 2024. To achieve the required sample size, twenty (20) fish were randomly sampled during each monthly visit from every aquaculture facility. With thirteen aquaculture facilities included in the study and twelve months of continuous sampling, this amounted to a total of 3,120 fish samples (20 fish × 13 facilities × 12 months).

Sampling

Purposive sampling was used to identify selected fish farms. The season were classified as shown in Table 1.

Table 1. Season classification for Uasin Gishu (May 2023–April 2024)

Season Label	Months Covered	Rationale
Long Rains	March - May 2024, May 2023	Period of peak rainfall characterized by intense nutrient runoff, increased turbidity, and fluctuations in water quality
Short Rains	October - December 2023	Period of moderate and variable rainfall, often resulting in less runoff than long rains but still affecting aquaculture facility ecosystems.
Low Rains / Dry Season	June - September 2023, January - February 2024	Period of minimal rainfall, leading to reduced water exchange, thermal stratification, and possible accumulation of metabolites in aquaculture facilities

Measurement of Physico-chemical parameters

Physico-chemical water quality parameters were measured in situ before

the collection of fish samples to establish the environmental conditions within each aquaculture facility. The parameters monitored included dissolved oxygen

(DO), temperature, pH, Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD), as these are important indicators of water quality and ecological balance in aquaculture systems. The measurements were taken at three-hour intervals between 0600 hrs and 1800 hrs. This approach allowed the study to capture both seasonal and diurnal variations in water quality, reflecting natural fluctuations influenced by factors such as solar heating, photosynthetic activity, and microbial processes.

Measurements were obtained using the Hach HQ40D multi-parameter portable meter fitted with Intellical digital probes, specifically the PHC301 for pH, the LDO101 for dissolved oxygen, and the CDC401 for conductivity and related parameters. The equipment was selected because of its precision, reliability in field conditions, and ability to store calibration data within the probes, thereby ensuring traceability and minimizing errors during operation.

Fish sampling

For the purpose of monitoring fish growth, six sampling sites were systematically established within each aquaculture facility. These included two sites strategically located near the water inlets, two situated in the central sections, and two positioned near the outlets. This spatial arrangement ensured that data collected captured the potential variability in environmental conditions and fish distribution across the facility, taking into account differences in water circulation, nutrient input, and dissolved oxygen gradients.

At each sampling event, a total of twenty fish were randomly captured from each aquaculture facility using a seine net (ENGEL-NETZE, Germany) with a mesh size of 10 mm. The choice of mesh size was deliberate to minimize injury to the fish while ensuring that individuals of varying sizes could be effectively sampled.

Random sampling was employed to avoid bias and to ensure that the data reflected the general growth performance of the entire fish population within the facility.

Once captured, the fish were immediately transferred into clean buckets containing water from the same facility to reduce handling stress and to maintain their natural physiological condition during the measurement process. Care was taken to avoid overcrowding in the buckets, and water was regularly replenished to maintain adequate oxygen levels, thereby minimizing fish mortality or stress-induced measurement errors.

Measurements of fish total length (TL) were taken to the nearest centimeter using plastic ruler, ensuring precision and consistency across all sampling events. Simultaneously, fish weights were determined using a weighing scale (Carsoe's, Denmark) with measurements recorded in grams. The use of standardized instruments minimized variability and guaranteed accuracy in growth data collection. All measurements were performed promptly after capture to further reduce stress on the fish.

Following the recording of biometric data, all fish were gently released back into their respective aquaculture facilities. The release process was carried out carefully to ensure that fish re-entered the water unharmed, thereby maintaining stock integrity and avoiding any negative effects on the ongoing culture operation.

Ethical Considerations

This study was conducted in accordance with recognized standards for responsible research. Prior to the commencement of fieldwork, ethical approval was obtained from the University of Eastern Africa, Baraton under reference Ser. No. B0102032023, dated 2nd March 2023. In addition, a research license was issued by the National Commission for

Science, Technology, and Innovation (NACOSTI) under License. No. NACOSTI/P/23/24545, dated 11th April 2023, authorizing the study in Uasin Gishu County.

Engagements were first made with the Uasin Gishu County Fisheries Department to introduce the research and clarify its scope. Sub-County Fisheries Officers further facilitated the identification of participating farms. Involvement of farmers and farm managers was entirely voluntary, and informed consent was obtained before any data collection activities. Participants were assured of confidentiality, and personal identifiers were excluded from all datasets, reports, and publications to ensure anonymity.

Fish were handled with care throughout the study, and only non-invasive procedures such as measurement of length, weight, and observation of general health condition were carried out. No dissections, invasive techniques, or experimental manipulations were performed. The welfare of fish was safeguarded by minimizing handling time and returning them promptly to their culture systems after measurement, in line with accepted aquaculture research practices.

All research data, including water quality measurements and fish growth results, were securely stored in password-protected digital files and lockable physical storage. Access to the data was restricted to the researcher and academic supervisors.

At all stages, the principles of respect, integrity, and responsibility guided the research process, ensuring protection of human participants, humane handling of fish, and reliability of the data generated. The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Statistical Analysis

Descriptive statistics (means, standard deviations, and ranges) were first generated for water quality and fish growth data. Normality of distributions was assessed using the Shapiro–Wilk test, and homogeneity of variances with Levene’s test, to confirm the suitability of parametric tests.

Differences in physicochemical parameters across farms, facility types, and seasons were tested using one-way ANOVA. Where significant effects were observed, Tukey’s HSD was applied for post-hoc comparisons. Diurnal variations in dissolved oxygen and temperature were analyzed through time-series plots of hourly surface and bottom measurements. For fish growth performance, length–weight relationships were estimated using the equation $W = \alpha L^b$, with growth type classified based on the allometric coefficient (b). Growth parameters (L^∞ , W^∞ , K , bK , CSC, GR) were estimated using the von Bertalanffy Growth Function (VBGF). Differences in growth among farms were assessed with ANOVA, while multiple linear regression was applied to compare growth across facility types. Growth curves (length and weight) were modeled using nonlinear regression and plotted for temporal patterns.

For Water Quality–Growth Relationship, multiple linear regression models were applied with maximum growth rate (Max GR) as the dependent variable and water quality parameters (temperature, DO, pH, COD, BOD) as predictors. Separate models were run for farms, facility types, and seasons. Model assumptions were checked (residual normality, multicollinearity), and significance was set at $p < 0.05$.

Results

Relationship between Water Quality and Fish Growth

The relationship between water quality and Fish growth across farms is as shown in Table 9. Fish growth varied with water quality, with BOD and COD being the most significant predictors. At Chebororwa Farm, both COD and BOD had significant effects on growth; COD was negatively associated ($p < 0.0001$), while BOD showed a positive association ($p = 0.0011$). A similar pattern was observed at

Cheplaskei Farm A, where both COD ($p = 0.0074$) and BOD ($p = 0.0004$) were significant. At Turbo Farm, BOD again had a significant positive effect on growth ($p = 0.0012$), and pH was also a significant positive predictor ($p = 0.0281$). At Cheplaskei Farm B, pH was negatively associated with growth ($p = 0.0022$), suggesting site-specific responses to water chemistry. At Talget Farm, none of the water quality parameters were statistically significant. Across all farms, temperature and dissolved oxygen (DO) consistently showed no significant influence on fish growth.

Table 2: Regression analysis of fish growth (Max GR) against water quality parameters across Farms

Farm	Water Quality Parameter	Coefficient	p-value	Significance
Chebororwa	Temperature	-0.0009	0.9538	NS
	Dissolved Oxygen	-0.0005	0.5771	NS
	pH	0.0045	0.8915	NS
	COD	-0.0056	0.0000	*
	BOD	0.0049	0.0011	*
Talget	Temperature	0.0139	0.1695	NS
	Dissolved Oxygen	-0.0016	0.0922	NS
	pH	0.0008	0.9818	NS
	COD	-0.0005	0.4753	NS
	BOD	0.0005	0.3443	NS
Cheplaskei A	Temperature	0.0108	0.6553	NS
	Dissolved Oxygen	0.0040	0.1111	NS
	pH	-0.0241	0.1005	NS
	COD	-0.0023	0.0074	*
	BOD	0.0020	0.0004	*
Cheplaskei B	Temperature	0.0035	0.1934	NS
	Dissolved Oxygen	0.0002	0.5674	NS
	pH	-0.0293	0.0022	*
	COD	0.0002	0.5761	NS
	BOD	0.0003	0.2012	NS
Turbo	Temperature	0.0018	0.9025	NS
	Dissolved Oxygen	-0.0002	0.8589	NS
	pH	0.1354	0.0281	*
	COD	0.0013	0.1516	NS
	BOD	0.0028	0.0012	*

Fish growth (Max GR) varied with water quality across aquaculture facility types, with COD and BOD again being the most consistently influential predictors, as shown in Table 10. In earthen aquaculture facility systems, both COD ($p < 0.0001$) and BOD ($p = 0.0006$) were statistically significant. COD had a negative effect, while BOD was positively associated with growth. Other parameters (Temperature, DO, and pH) were not significant in this facility type. In liner aquaculture systems,

multiple predictors were significant. DO showed a significant negative association with growth ($p = 0.0135$), while both pH ($p < 0.0001$) and COD ($p = 0.0005$) had strong positive and negative effects, respectively. BOD and temperature were not significant. In the tank systems, both COD ($p = 0.0012$) and BOD ($p < 0.0001$) were again significant and positively associated with fish growth, while Temperature, DO and pH had no significant impact.

Table 3: Regression analysis of fish growth (Max GR) against water quality parameters by aquaculture facility type

Facility Type	Water Quality Parameter	Coefficient	p-value	Significance
Earthen	Temperature	-0.0108	0.1335	NS
	Dissolved Oxygen	0.0008	0.1803	NS
	pH	-0.0287	0.1008	NS
	COD	-0.0029	0.0000	*
	BOD	0.0028	0.0006	*
Liner	Temperature	0.0053	0.7572	NS
	Dissolved Oxygen	-0.0035	0.0135	*
	pH	0.4683	0.0000	*
	COD	-0.003	0.0005	*
	BOD	-0.0007	0.4492	NS
Tank	Temperature	0.0924	0.0510	NS
	Dissolved Oxygen	0.003	0.2805	NS
	pH	-0.0158	0.3292	NS
	COD	0.0034	0.0012	*
	BOD	0.0043	0.0000	*

Fish growth (Max GR) exhibited season-specific responses to water quality parameters, with BOD and pH emerging as the most significant predictors in different seasons, as shown in Table 11. During the Dry Season, BOD showed a strong positive association with growth ($p = 0.0012$), indicating that biologically available organic matter enhanced productivity under low rainfall conditions. Additionally, both pH ($p = 0.0126$) and dissolved oxygen (DO) ($p = 0.0401$) were significant, with pH positively and DO negatively associated with growth. Temperature and COD were

not significant in this period. In the season with long rains, only BOD remained a significant predictor ($p = 0.0192$), again indicating the importance of organic content during peak rainfall. Other parameters, including Temperature, pH, DO, and COD, did not significantly affect growth.

During the short rains, pH was the only significant predictor of growth ($p = 0.0266$), showing a strong positive relationship. All other parameters, including BOD, COD, DO, and temperature, were statistically non-significant.

Table 4: Regression analysis of fish growth (Max GR) against water quality parameters across seasons

Season	Predictor	Coefficient	p-value	Significance
Dry Season	Temperature	0.0349	0.3019	NS
	Dissolved Oxygen	-0.0057	0.0401	*
	pH	0.0418	0.0126	*
	COD	-0.0026	0.0930	NS
	BOD	0.0060	0.0012	*
Long Rains	Temperature	0.0953	0.0711	NS
	Dissolved Oxygen	-0.0052	0.1802	NS
	pH	0.1641	0.1108	NS
	COD	-0.0011	0.5802	NS
	BOD	0.0048	0.0192	*
Short Rains	Temperature	0.0079	0.8745	NS
	Dissolved Oxygen	-0.0025	0.5774	NS
	pH	0.3700	0.0266	*
	COD	-0.0001	0.9806	NS
	BOD	0.0006	0.8643	NS

Discussion

Water quality plays a crucial role in determining fish growth in aquaculture. The results indicate that certain water quality parameters, particularly BOD, significantly influence fish growth, while others, such as dissolved oxygen and pH, showed weaker or statistically insignificant correlations.

BOD is a key indicator of the amount of organic matter in water that can be decomposed by microorganisms. Elevated BOD levels indicate higher concentrations of organic waste, such as uneaten feed, fish excreta, and other decomposable materials, which stimulate microbial activity. As microorganisms break down this organic matter, they consume dissolved oxygen, thereby reducing the oxygen available for fish. This oxygen reduction can stress the fish, lower their metabolic efficiency, decrease feed intake, and ultimately slow growth rates. High BOD levels are also associated with the accumulation of nitrogenous compounds, including ammonia and nitrites, which are toxic to fish at elevated concentrations and can further inhibit growth. Additionally, excessive microbial

activity resulting from high BOD can alter water chemistry and produce harmful metabolites, indirectly affecting fish health. Therefore, maintaining moderate BOD levels in aquaculture ponds is essential, as it ensures sufficient oxygen availability while supporting balanced microbial activity, which in turn promotes optimal growth in *O. niloticus*.

The study found that temperature exhibited a weak but statistically significant association with fish growth. The regression analysis also showed a positive but marginally significant effect of temperature on fish weight. These findings align with research by Makori *et al.*, (2017), who observed that temperature influences fish metabolic rates, digestion efficiency, and growth performance. However, the relatively weak association in this study suggests that other factors, such as farm management practices and feed availability, may have played a more dominant role in influencing fish growth.

Temperature is a fundamental environmental factor that directly affects the physiology and metabolism of fish. *O.*

niloticus is an ectothermic organism, its body temperature closely follows that of the surrounding water, meaning that fluctuations in water temperature can influence metabolic processes, feeding behavior, and energy utilization. At optimal temperature ranges, metabolic rates are enhanced, supporting efficient digestion, nutrient absorption, and growth. Temperatures that are too low can slow metabolism, reduce appetite, and impair enzymatic activity, resulting in slower growth rates (Wambua et al., 2021). High temperatures, on the other hand, may increase metabolic demand and oxygen consumption, potentially leading to stress if dissolved oxygen is limited, which can also constrain growth.

Temperature also interacts with other environmental and management factors. For instance, optimal feeding efficiency and feed conversion are often realized only when water temperature supports active metabolism. Extreme or fluctuating temperatures can exacerbate the effects of suboptimal water quality, limited feed availability, or poor pond management, further influencing growth outcomes. Therefore, while the study found only a weak but statistically significant association between temperature and fish growth, this does not diminish its biological importance. It highlights that temperature sets the physiological context within which other factors, such as feed quality, stocking density, and overall farm management, operate to determine the growth performance of tilapia.

DO showed a weak negative association with fish growth and was not statistically significant. This contradicts previous studies' findings suggesting DO is a key determinant of fish health and growth (Welker et al., 2019). The lack of a strong association in this study may be due to variations in aeration practices among farms, which could have mitigated the adverse effects of low DO levels.

DO is one of the most critical water quality parameters influencing fish growth and survival. Fish rely on DO for respiration, which provides the energy required for essential physiological processes, including metabolism, digestion, and activity. When DO levels are optimal, fish can efficiently metabolize feed, grow rapidly, and maintain good health (Ibearugbulem et al., 2024). Low DO levels, however, can induce stress, reduce feed intake, and impair nutrient assimilation, leading to slower growth rates and increased susceptibility to disease. Prolonged exposure to hypoxic conditions can even result in mortality, particularly in dense aquaculture systems where oxygen demand is high.

According to (Wanja et al., 2020) DO levels interacts with other water quality parameters, for example, high water temperatures increase metabolic oxygen demand, making fish more sensitive to low DO. Aeration and water circulation practices can mitigate these effects by maintaining adequate oxygen levels, even in ponds with high organic load or temperature fluctuations. Therefore, while the study observed only a weak and statistically insignificant association between DO and fish growth, this may reflect effective aeration that compensated for low DO, rather than indicating that oxygen availability is unimportant for *O. niloticus* growth.

pH and salinity showed weak or non-significant correlations with fish growth. The variations in pH observed in this study may not have been extreme enough to exert a significant effect. During the study salinity, which can influence osmoregulation in fish, did not exhibit a notable impact on fish growth in aquaculture facilities. The pairwise correlation matrix plot further supports these findings, indicating that pH, salinity, and DO have minimal direct influence on fish weight.

pH is a fundamental water quality parameter that affects the physiological and biochemical processes of *O. niloticus*. Optimal pH levels, generally ranging from 6.5 to 9.0 support proper enzymatic activity, efficient nutrient absorption, and overall metabolic function in fish (Mramba & Kahindi, 2023). When pH falls outside this optimal range, fish may experience stress, reduced feed intake, and impaired digestion, which can negatively affect growth. Extremely low or high pH can also disrupt gill function, interfere with ion balance, and increase the toxicity of certain chemicals or nitrogenous compounds in the water, further compromising health and growth performance. In contrast, moderate fluctuations within the optimal range often have minimal impact, as fish possess physiological mechanisms to tolerate small deviations. In the context of aquaculture, maintaining a stable pH within the suitable range ensures that *O. niloticus* can efficiently utilize feed, sustain healthy metabolic activity, and achieve optimal growth rates (Ruben et al., 2025).

Furthermore, while temperature showed a weak correlation, its potential role in fish growth suggests that monitoring seasonal variations and implementing strategies such as shading or aeration could help maintain stable thermal conditions. Additionally, maintaining DO levels through proper aeration, even if not significantly correlated in this study, remains essential for overall fish health and disease prevention (Kongprajug *et al.*, 2021).

Conclusions and Recommendations

This study aimed to assess water quality and fish growth performance across selected fish farms in Uasin Gishu County. The findings provide insights into the interconnections between these

factors and their implications for aquaculture development in the region. The study established that farms and aquaculture facilities that consistently maintained optimal ranges of dissolved oxygen, biological oxygen demand, chemical oxygen demand, pH, and temperature achieved superior growth outcomes. This highlights the importance of proper water quality monitoring and management as a strategy for sustainable aquaculture production.

Based on the study's findings, several recommendations are proposed to strengthen aquaculture practices in Uasin Gishu County. To begin with, fish farmers should prioritize the consistent monitoring and regulation of key water quality parameters such as dissolved oxygen, pH, and temperature in order to sustain favorable growth conditions. The implementation of routine water testing protocols, supported by timely corrective measures, is essential in minimizing adverse fluctuations that may compromise fish health and performance. To make this more practical, provision of subsidized water testing kits alongside farmer training on their proper use would further enhance effective water quality management.

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